COMPARISON OF STATIC RESPONSE OF SELF-COMPACTING CONCRETE (SCC) AND CONVENTIONAL VIBRATED CONCRETE (CVC)

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by

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CERTIFICATION OF APPROVAL

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JANUARY 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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NURAIHAN BINTI KAMARUDIN

ABSTRACT

This report basically provides the discussion on the research done and basic understanding of the chosen topic, which is **Comparison of Static Response of Self-compacting Concrete (SCC) and Conventional Vibrated Concrete (CVC).** An experimental investigation is conducted to study the static response of several beam specimens made with self-compacting concrete (SCC) as well as Conventional Vibrated Concrete (CVC). Lab testing was done for the designed mix for fresh properties of concrete as well as the hardened concrete. The fresh concrete was tested for its workability, viscosity and resistance to segregation. Once the concrete has hardened, the best mix was chosen to cast a total of 6 concrete beam specimens (3 SCC beams and 3 CVC beams). This total of 6 concrete beam specimens, were tested under 4-points flexure test for static loads with 3 different rates until failure occurred. The performance of SCC/CVC beams was evaluated under influence of fracture strength based on the results of crack pattern, loads at the first flexure/diagonal cracking and ultimate static loading resistance of the concrete.

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ABBREVIATIONS

SCC	Self-Compacting Concrete
CVC	Conventional Vibrated Concrete
UTM	Universal Testing Machine
OPC	Ordinary Portland Cement
BS	British Standard
IS	Indian Standard

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Since 1983, the dilemma of durability in concrete structure was a huge attention in Japan due to the reduction in number of skilled workers as the durable concrete structures requires sufficient compaction by them. Hence, Okamura (1986) has come up with a new advancement in concrete technology which known as Self-Compacting Concrete (SCC). Later, Ozawa (1989), Okamura (1993) and Maekawa (1999) have carried out several studies to develop SCC, including a fundamental study on workability of concrete at the University of Tokyo. The first prototype of SCC is completed in 1988 and named as High Performance Concrete (HPC). Ouchi (2003) has stated that HPC is defined at the three stages of concrete:

1. Fresh: Self-compactable
2. Early age: Avoidance of initial defects
3. Hardened: Protection against external factors

The main reasons for the employment of self-compacting concrete can be summarized as follows (Ouchi 2003):

1. to shorten construction period
2. to reduce labour cost
3. to assure compaction in the structure, especially in the confined zones where vibrating compaction is difficult
4. to eliminate noise due to vibration, effective especially at concrete production plants

1.2 PROBLEM STATEMENT

1.2.1 Problem Identification

According to Ouchi (2003), various researches had been done in universities, large construction companies and material maker to produce a standard Self-Compacting Concrete (SCC) which has the characteristics of high flowability and workability during its fresh (plastic) state, but very strong and durable once it has hardened. SCC has different durability expected due to the different mix design and the absence of vibration in comparison with Conventional Vibrated Concrete (CVC) (RILEM 2008).

There has been a little discussion regarding of hardened properties as compared to fresh properties of SCC but still, the strength of hardened SCC is considered to be as equal as CVC. However, the application of SCC is expected to improve the flexural behaviour, increase the concrete and reinforcement bond and the confinement effect directly (Fernando et al. 2008).

The employment of SCC in actual structures has gradually increased since the development of its first prototype in 1988. For many years, there are several situations where concrete has to be placed in such difficult situations to achieve its compaction such as in situ beam concreting, under water concreting, filling of congested sections and many other inaccessible areas. These situations cause the decreasing of strength and durability performance, resulted inhomogeneous and nonuniform concrete production regardless of how well the design is (J.Annie et al. 2006).

1.2.2 Significance of the Project

In this project, the investigation will be focused on studying the static response of SCC as compared to CVC through a fracture mechanics-based flexural test by using Universal Testing Machine (UTM). The static behaviour in compression and tension of SCC in comparison to Conventional Vibrated Concrete (CVC) beams were evaluated on six different beam specimens with 3 samples specimens for each type of concrete. These beam specimens will be tested on three different rates of static loading.

1.3 OBJECTIVE AND SCOPE OF STUDY

1.3.1 The relevancy of the project

The main objectives of this research are:

- To design the beam specimens by using the best mix proportion for both CVC and SCC under the influence of fracture strength.
- To experimentally study the comparison of static load response under 3 different rates between CVC and SCC through a fracture mechanics-based flexural test.
- To identify any other element related to this topic such as crack propagations/patterns, etc.
- The establishment of any relationship on crack propagations and failure load on both types of concrete beams.

1.3.2 Scope of Study

The scope of work for this project is to investigate the result of SCC outcome when subjected to static loading. The investigation will cover two types of tests namely; the fresh concrete test and hardened concrete test. These tests shall simulate the performance of SCC under the influence of fracture strength in the real application of concrete structures. The performance of SCC and CVC beams were evaluated based on the results of time failure, deflection, crack pattern, crack propagation and maximum sustainable loads of SCC.

CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

Conventional Vibrated Concrete (CVC) consists of combination of different composition of construction materials such as cement, aggregates, water, admixture/additives and cement replacement materials. The composition of concrete is determined initially during mixing and finally during placing of fresh concrete. The type of structure being built and the method of construction determine the composition of the concrete mix and how the concrete is placed.

The application of the different types of concrete by virtue of its density depends on the structures to be cast. Heavy weight normally meant for structures resting on the ground and capitalizing its weight to withstand pressure from the loads. The heavy weight comes from aggregates. CVC is for general construction of concrete structures (A.M. Neville 2005).

Various types of concrete have been developed for specialist application and the most common ones are regular concrete, self-compacting concrete and asphalt concrete. Self-compacting concrete (SCC) are characterized by their extreme fluidity, behaving more like a thick fluid that is self levelling, as opposed to conventional concrete that needs consolidating which are normally vibration or packing

2.2 SELF-COMPACTING CONCRETE

According to RILEM (2008), Self-compacting concrete (SCC) also known as Self-Consolidating Concrete in North-America can be defined as an innovative concrete that able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement without any vibration requirement for placing and compaction. SCC mixes must meet three key properties (RILEM 2008):

1. Ability to flow into and completely fill intricate and complex forms under its own weight
2. Ability to pass through and bond to congested reinforcement under its own weight
3. High resistance to aggregate segregation

According to Brouwers (2005), the Japanese Method suggested that the gravel content in concrete mix correspond to 50% of its packed density and that in the mortar, the sand content corresponds to about 50% of its packed density. Ozawa (1989) and Okamura (1993) have employed the following methods to achieve self-compatibility (Brouwers et al. 2005):

1. Limited aggregate content
2. Low water-powder (*w/p*) ratio
3. Use of superplasticizer

2.3 MIX PROPORTION & MATERIAL USED

For several years, many have studied the wide range of mix proportions (optimum mix design) that can result positive outcomes for SCC (Okamura and Ouchi 2003). But the composition requires a certain limiting amount of values expressed in volumetric terms (RILEM 2008):

- A coarse aggregates volume: 30% - 34% of concrete volume
  (Normal workability concrete: 40% - 45%)
- A water/powder ratio (*w/p*): 0.8-1.2
  (Contains a viscosity agent at the upper end of this range)
- A water content: 155-175 $1/m^3$ (excluded viscosity agent)
  : 200 $1/m^3$ (included viscosity agent)
- A paste volume: 24%-40% of concrete volume
- A fine aggregates volume: 40%-50% of mortar volume

Basically, SCC requires a higher amount of ultrafine material and chemical admixtures are incorporated together with it such as super plasticizer. The difference between CVC and SCC are shown in Figure 2.1 (Klaus and Klug 2002):

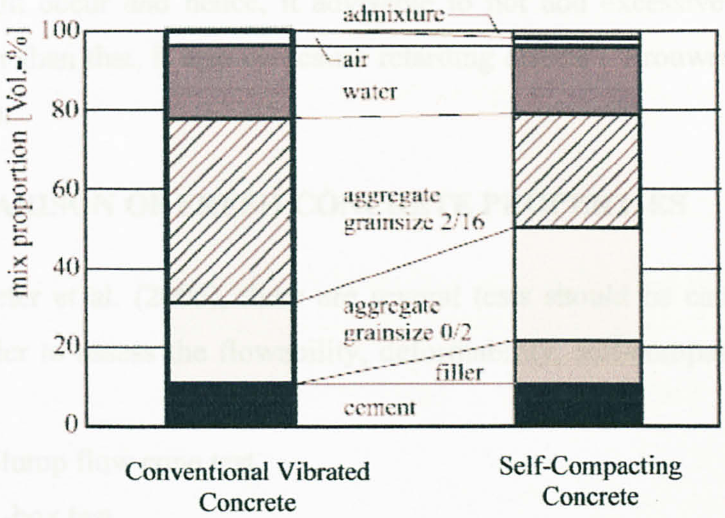


Figure 2.1: Mix composition of CVC in comparison with SCC

A good and durable concrete mix design relies on the state-of-the-art knowledge. It requires many years of experience on normal concrete itself.

In the previous experiment, for concrete piles specimen, Grade 53 Ordinary Portland cement (OPC) was used to investigate the static behaviour of SCC. But this value conforms with IS (Indian Standard) instead of British Standard (BS), with consistency of 31%, initial and final setting times of 110minutes and 150minutes, and a compressive strength of 54MPa determined as per IS standard. The fine and coarse aggregates are obtained from locally river sand (specific gravity of 2.7; fineness modulus of 2.83) and crushed granite aggregate (specific gravity of 2.85 and fineness modulus of 6.24) respectively with the maximum size of coarse aggregate of 12.5mm (J.Annie 2006).

2.4 SUPER PLASTICIZER

Super plasticizer is described as high range water reducer or chemical admixture added which will act to improve the workability of SCC. The presence of super plasticizer is vital as the amount of water-cement (w/c) ratio is less or limited which makes the concrete mixture is unworkable and harder to mix due to the reason of achieving higher strength of concrete (Nan Su et al. 2001).

2% of super plasticizer per unit weight of cement is enough amounts to be added in SCC. But due to the reason that most of commercial super plasticizer comes as dissolved in water causes the presence of extra water added in mix proportioning, the excessive segregation might occur and hence, it advisable to not add excessive amount of super plasticizer. Other than that, it also can cause retarding effects (Brouwers 2005, Okamura and Ouchi 2003).

2.5 COMPARISON OF FRESH CONCRETE PROPERTIES

According to Peter et al. (2006), there are several tests should be carried using special apparatus in order to assess the flowability, deformability, self-compatibility, and filling ability of SCC:

1. Slump flow cone test
2. L-box test
3. U-box test
4. V-funnel Test
5. Filling ability test

The results obtained are shown in Table 2.1 with the recommended value suggested by other investigators (J.Annie 2006).

Table 2.1: Test Results on Fresh Concrete Properties of SCC

Fresh concrete test methods	Recommended value	Observed value
Slump flow (time taken) (Saak et al. 2001)	60–75 cm in 10±3 s	70 cm in 5 s
	50 cm in 5±2 s	50 cm in 3 s
L-box (Yonezawa et al. 1989)		
20 cm	1.0±0.5 s	1 s
40 cm	2.5±0.5 s	2 s
$h_2{}^a/h_1{}^b$	0.8–1.0	0.85
V funnel (flow time) (Ozawa et al. 1995)	8–12 s	10 s
U-box (filling height) (Saaka et al. 2001)	>30 cm	33 cm
Filling ability $A/(A+B)$ value (Yurugi and Sakai 1998)	90–100%	92%

[a] Height of concrete at final stage.
[b] Height of concrete at initial stage.

2.6 COMPRESSIVE STRENGTH

The water to cement is nearly the same in both mixes regardless of higher the quantum of water per unit volume of concrete in SCC. This leads to similar development of compressive strength in the SCC and CVC up to age of 28days, as seen in Table 2.2 (J.Annie 2006):

Table 2.2: Mechanical and Durability Properties of SCC and CVC Mixes

Properties	Age (days)	SCC	CVC
Mechanical properties			
Compressive strength (MPa)	1	18.3	19.3
	3	39.8	37.1
	7	54.2	46.8
	28	70.1	69.4

.

It may be noted here that with the value strength level of 60MPa, CVC can be considered as reasonably durable. This also applies in SCC mix which also indicates as comparable durability result for compressive strength. Hence, SCC mix can also be considered as durable, despite the presence of higher level of water and fine contents. Hence, it was necessary to establish that SCC mixes had durability related properties which were similar or superior to that CVC (J.Annie 2006, Klaus and Klug 2002).

2.7 STATIC LOAD RESPONSE

Static load can be defined as a type of load which does not undergo a change in magnitude or direction during a measurement procedure. It is basically an external force that is applied and held in a fixed position for a specific amount of time (J.Annie 2006).

Failure load mode can exist due to various reasons such as due to inadequate compressive or fracture strength and a reduction in its durability (Wittmann 2002, J.Annie 2006, RILEM 2008). System failure takes place when load exceeds capacity by an unacceptable amount. To study static load response, tests on hardened SCC should be conducted. The evaluation of the failure load will be under the monotonic/static load flexural test (RILEM 2008).

2.8 FRACTURE BEHAVIOUR

Fracture can be defined as the act of breaking or state of being broken. Fracture behaviour very much deals with the tensile and compressive strengths, ductility and durability of SCC. Fracture in concrete is caused by mechanical interaction between the coarse aggregates and the cement-based matrix (Wittmann 2002). Fracture energy can be influenced by several factors such as maximum aggregate size (Wittmann 2002), heat curing and also paste volume i. e. water, aggregates and admixture contents (Roziere et al. 2007).

2.9 GENERAL CRACKING PATTERNS / PROPOGATIONS

In general, SCC beams generate slightly less number of cracks as compared to CVC beams. The number of diagonal shear cracks is also lower in SCC as compared to CVC beams. Larger size of SCC/CVC beams have more cracks and develop higher diagonal crack widths at failure irrespective of reinforcement ratio (1% or 2%). The larger sizes of SCC/CVC beams are also causing the sudden failure as compare to small ones (A.A.A Hassan et al. 2008)

As stated by A.A.A Hassan et al. (2008) in their paper, for both SCC and CVC beams, the cracks extended up to 50% and 70% of the failure load, respectively. The angle for the early diagonal dominant cracks was around 55° (to the beam longitudinal axis) while that for the failure diagonal crack was 35°.

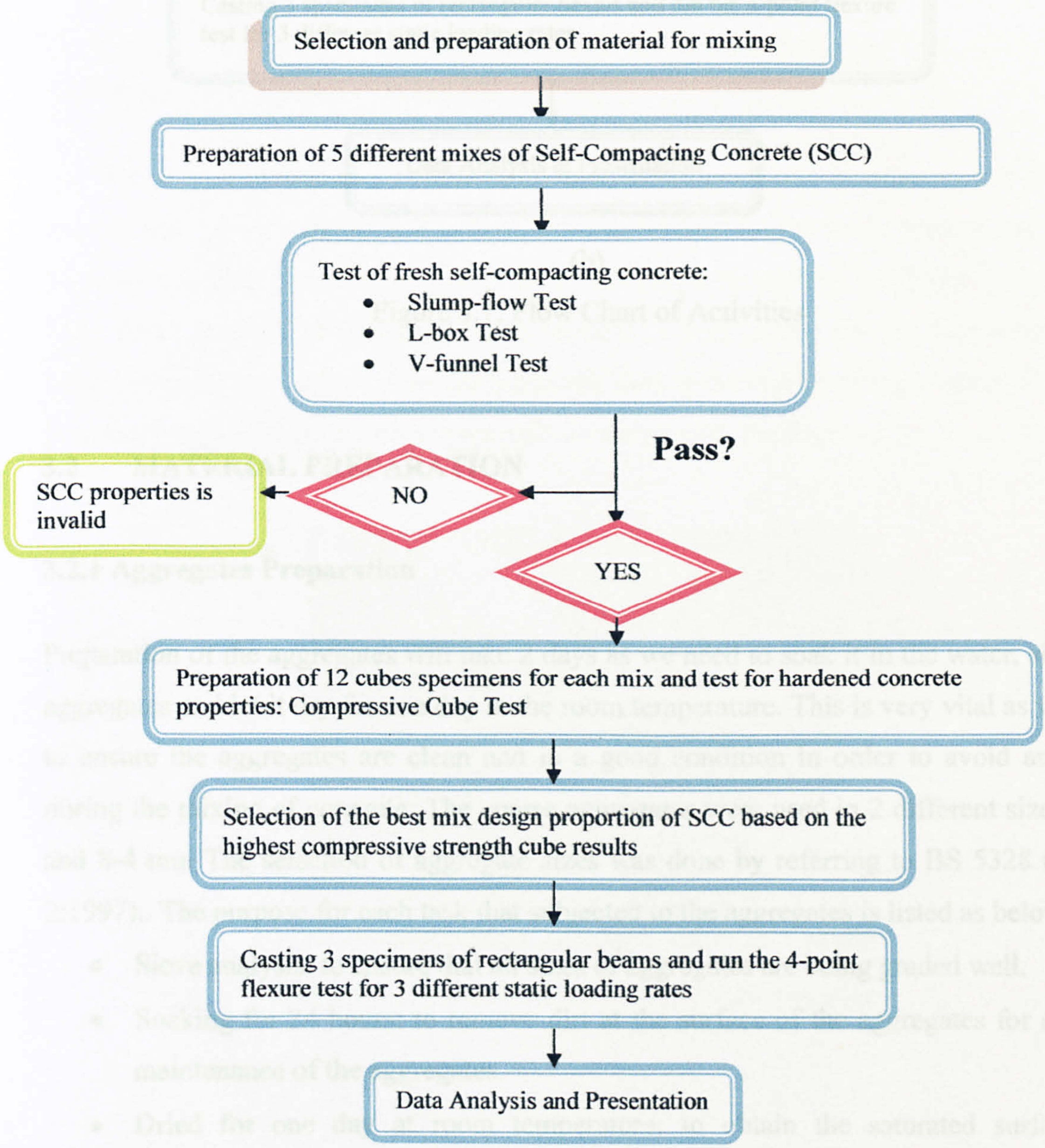
CHAPTER 3

METHODOLOGY

3.1 PROJECT IDENTIFICATION

The general sequence of methodology showed as in Figure 3.1 (a) and (b):

Self-Compacting Concrete



(a)

Conventional Vibrated Concrete

Selection and preparation of material for mixing

↓

Mixing the concrete using the best mix design proportion for Conventional Vibrated Concrete (CVC), having similar strength (comparable) to SCC

↓

Casting 3 specimens of rectangular beams and run the 4-point flexure test for 3 different static loading rates

↓

Data Analysis & Presentation

(b)

Figure 3.1: Flow Chart of Activities

3.2 MATERIAL PREPARATION

3.2.1 Aggregates Preparation

Preparation of the aggregates will take 2 days as we need to soak it in the water, sieve the aggregates and let it dry for one day at the room temperature. This is very vital as we need to ensure the aggregates are clean and in a good condition in order to avoid any error during the mixing of concrete. The coarse aggregates were used in 2 different sizes; 20-8 and 8-4 mm The selection of aggregate sizes was done by referring to BS 5328 (Part 1-2:1997).. The purpose for each task that subjected to the aggregates is listed as below:

- Sieve analysis: to ensure that all sizes of aggregates are being graded well.
- Soaking for 24 hours: to remove dirt at the surface of the aggregates for strength maintenance of the aggregates.
- Dried for one day at room temperature: to obtain the saturated surface dry aggregates.

3.2.2 Ordinary Portland cement (OPC) Preparation

Cement is a powder, which by hydraulic reaction (i.e with water) forms a solid, cohesive mass. OPC is the standard cement which is grey in color. It is complex mixture of chemical reaction between dicalcium and tricalcium silicates (C_2S and C_3S). Besides, it also consists of tetracalcium aluminoferrite (A.M Neville 2005). Choosing the right type of OPC was in accordance to BS 5328 (Part 1-2:1997).

3.2.3 Material for Beam Specimens

For this project, it requires several beam specimens to be cast in order to run the static loading test. There were several materials to be prepared for the beam casting task such as plywood and nails (formwork), 12mm of Y bars (yield strength of 460N/mm^2), 6mm of R links (mild strength of 250N/m^2) and lubricant oil as grease for the formwork's wall before pouring the concrete into the formwork during the beam casting process. Complete formwork with all the materials prepared for casting as in the Figure 3.2.

Figure 3.2: Formwork for casting beam specimens.

3.3 MIX DESIGN PROPORTION

Two types of concretes were made: Self-compacting concrete (SCC) and Conventional Vibrated Concrete (CVC). Five different mixes were prepared based on different amount of water-cement (w/c) ratio and super plasticizer. The best mix proportion is very significant as it will lead to the high performance of the SCC characteristics.

Table 3.1: Mix Design per m^3

Name	Mix No	OPC (kg)	CA (20-8) (kg)	CA (8-4) (kg)	FA (kg)	w/c	water (kg)	S/P (%)	S/P Wt. (kg)	Total (kg)	% coarse	% fine agg.
SCC	1	500	325	610	815	0.30	150	3	15	2400	53.43	46.57
	2	500	310	600	815	0.35	175	3	15	2400	52.75	47.25
	3	500	295	590	815	0.40	200	3	15	2400	52.06	47.94
	4	500	280	585	810	0.45	225	3	15	2400	51.64	48.36
	5	500	265	575	810	0.50	250	3	15	2400	50.91	49.09
Control (CVC)		500	290	590	820	0.4	200	0	0	2400	51.76	48.24

3.4 SPECIMEN DETAILS

3.4.1 Cube Specimens

The best mix proportion was selected through cube compressive strength test. The test requires cube specimens of 100mm × 100mm × 100mm. Three batches were prepared for every mix of SCC that passed the SCC fresh properties test.

Figure 3.3: 100mm × 100mm ×100mm cube specimens

3.4.2 Beam Specimens

Six reinforced concrete beams (3 made with SCC and another 3 made of CVC), designed only for adequate flexural reinforcement and shear reinforcement were tested. Figure 3.4 and Figure 3.5 show the geometric dimensions of SCC and CVC beams. All beams were 150mm wide (*b*) with total depth (*h*) of 250mm with the length of 1900mm. The span to total depth ratio (*b/h*) was kept constant lower than 2.5 to ensure bending failure of all beams rather than shear failure (Shallow beam) (A.A.A Hassan 2008). The flexural reinforcement configurations were used for the beams with reinforcement ratios of 1%. 4 nos. of 12mm diameter Y bars and 12 nos. of 6mm diameter R links were used as reinforcement for each specimen. Cross-sectional dimension and reinforcement layout of beam are shown in Figures 3.4 and 3.5.

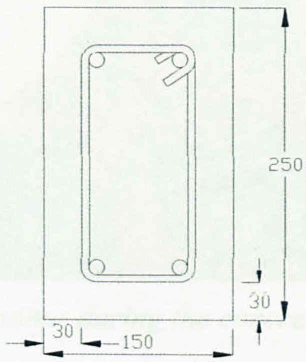


Figure 3.4: Cross sections and reinforcement layout of beams.

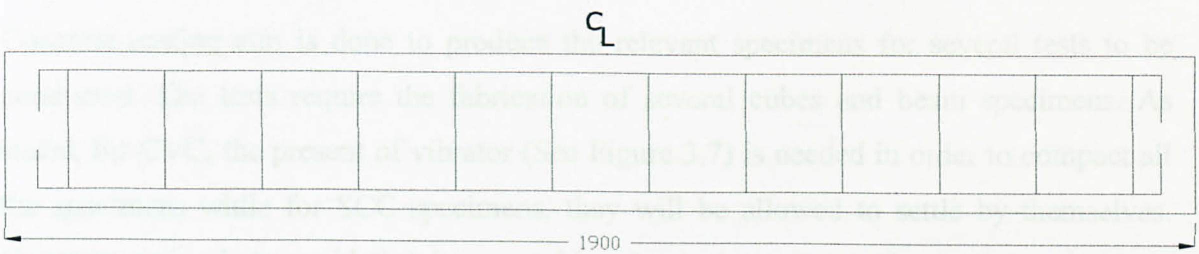


Figure 3.5: Dimension use for all beam specimens.

3.5 CONCRETE MIXING

All concrete should be mixed thoroughly until it is uniform. The sequence of concrete mix plays vital role and it is compulsory to be followed. The sequence of concrete mix is very important to make sure the mix is uniform. The procedures followed as per BS 1881 (Part 125:1986) as listed:

1. Wetted the mixer with water
2. Pour all coarse and fine aggregates into the mixer and mix for 25 seconds to ensure uniform distribution between both materials.
3. Pour half of the water and mix for 1 minute.
4. Leave the mixes for 8minutes to let the both coarse and fine aggregates to absorb water.
5. Pour all Portland cement into the mixer and mix for 1 minute.
6. Pour another half of the water and mix for 1 minute.
7. Lastly perform hand mixing until the mix in uniform stage (See Figure 3.6).

Figure 3.6: The author during the concrete mixing process

3.6 CONCRETE CASTING AND CURING

Concrete casting aim is done to produce the relevant specimens for several tests to be conducted. The tests require the fabrication of several cubes and beam specimens. As stated, for CVC, the present of vibrator (See Figure 3.7) is needed in order to compact all the specimens while for SCC specimens, they will be allowed to settle by themselves. Concrete curing is to avoid shrinkage cracking due to temperature fluctuation and also to gain maximum strength of the concrete.

Figure 3.7: Vibrator is used during the casting process of CVC specimens.

3.6.1 Cube Specimens

A total of 12 cubes were cast using 100mm × 100mm ×100mm mould for each mix that will be tested on fresh properties and continued with hardened properties test later if it succeeded the SCC fresh properties tests. After concrete cube is hardened, it will be cured by soaking them inside water container (See Figure 3.8). Curing means to cover the concrete so it is moisturized. By keeping concrete moist the bond between the paste and the aggregates gets stronger. Concrete doesn't harden properly if it is left to dry out. Concrete get harder and stronger over time. The longer concrete is cured, the closer it will be to its best possible strength and durability (RILEM, 2008).

Figure 3.8: 100mm × 100mm ×100mm cube specimens soaked in water

3.5.2 Beam Specimens

A total of six concrete beam specimens (3 made with SCC and 3 with CVC), designed with adequate flexural reinforcement and shear reinforcement were tested. The dimension for beam specimens is 150mm wide, 250mm high and 1900mm long. Procedures for concrete casting are:

1. Grease was used to prevent the concrete mix from sticking to the formwork by brushing the grease to the formwork surface.
2. The concrete was poured into the formwork by three layers. (Vibrator was used to take out the air trapped in the concrete mix for every layer in CVC beams).
3. After one day, the beams were ready for curing process.

Figure 3.9: Jut bags were used to provide moisture to the beams.

During the beams curing process, wetted jut bags (See Figure 3.9) were used to make sure the concrete beam in the moisturized condition and water was sprayed for every two days to make sure the beams in wet condition and hydration were taking place.

3.7 FRESH CONCRETE TEST

There were three purposes for self-compactibility tests relating to practical purposes, which were to check whether or not the concrete was self-compatible, to adjust the mix proportion, and to characterize the materials.

3.7.1 Slump-flow test

This test is to see the workability and deformability of concrete. No compaction energy must be applied during the test so that the SCC flows only under the influence of gravity. The slump flow is influenced primarily by the yield value of the concrete. The lower the yield value the larger is the extended circle of concrete formed. The yield value depends in turn mainly on the degree of agglomeration of the fine constituents in the concrete, which can be reduced most effectively with superplasticizers. The slump flow is therefore primarily suitable for assessing the yield value of the SCC and the optimum superplasticizer content (G. De Schutter 2005).

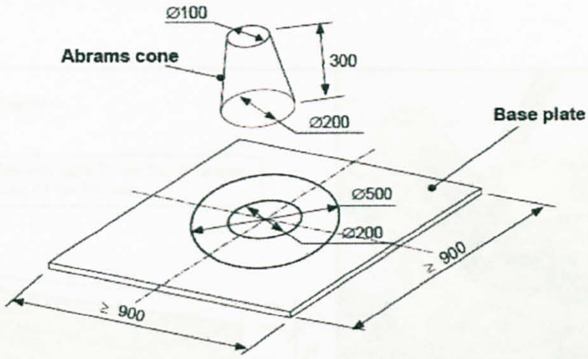


Figure 3.10: The Base Plate and Abrams Cone used in the Slump Flow Test

Figure 3.11: Slump Flow Test

The procedure is to pour the fresh concrete into a standard slump cone known as Abrams Cone. Then, withdraw the cone vertically upwards in one movement, without interfering with the flow of concrete. Without disturbing the base plate or the concrete, the largest diameter of the flow spread to the nearest 10mm is taken. (G. De Schutter 2005). Then the diameter of the flow spread at right angles to it is measured, and the mean of the reading is the slump (See Figures 3.10 and 3.11).

3.7.2 L-Box test

This test is to detect the concrete with higher possibility of segregation between coarse aggregate and mortar also for assessing the placeability of SCC. In this method a closed vertical chamber is filled with the concrete to be tested so that a hydrostatic pressure head is produced. After a slide is opened the concrete has to level out through horizontal (L-box) flow obstacles (See Figures 3.12 and 3.13). The difference in levels determines the tendency to blocking (G. De Schutter 2005).

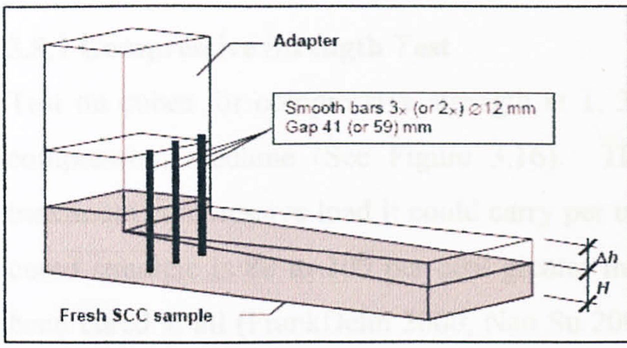


Figure 3.12: Principle of L-box Test

Figure 3.13: L-box Test

3.7.3 V-funnel Test

V-funnel test is to test for viscosity of concrete. The viscosity of a suspension is dependent mainly on the water/solids ratio and the overall grading curve. This means that a SCC with higher water content flows faster out of the funnel and has a lower viscosity than SCC with lower water content.

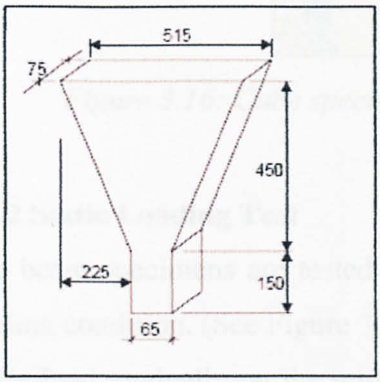


Figure 3.14: Dimensions of the V-funnel

Figure 3.15: V-Funnel Test

The procedure for this test is the funnel will be filled completely with the concrete and at the bottom outlet would then be opened, allowing concrete to flow out (See Figures 3.14 and 3.15). The time of flow recorded. Flow time can be associated with a low deformability due to high paste viscosity, high inter particle friction or blockage of flow. Flow time should be below then 10 seconds to be considered as Self-compacting Concrete (SCC) (G. De Schutter 2005).

3.8 HARDENED CONCRETE TEST

3.8.1 Compressive Strength Test

Test on cubes for compressive strength at 1, 3, 7 and 28 days by using the ADR 1500 compression machine (See Figure 3.16). The compressive strength is taken as the maximum compressive load it could carry per unit area. Compressive strength of properly cured concrete is 80 to 100 per cent greater than the strength of concrete which has not been cured at all (FrankDehn 2000, Nan Su 2001 and J.Annie 2006). An average reading from three different cube specimens is taken for each day of the tests which are 1, 3, 7 and 28 days for every mix batch.

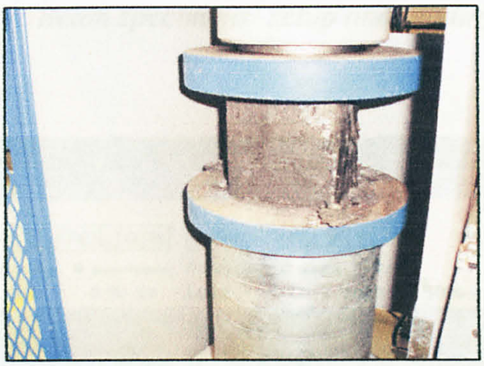


Figure 3.16: Cube specimens inside the compression machine (ADR 1500)

3.8.2 Static Loading Test

The beam specimens are tested as simply supported beams under four-point flexure test loading condition. (See Figure 3.17). The test setup including the use of hydraulic jack that apply load gradually on the mid span of beam specimens until it fails. A computer aided data acquisition system automatically monitored load at pre-selected time intervals throughout the test. The test also provided information on the overall behaviour of the beams including development of cracks, crack patterns and propagations and failure modes. For rectangular beams, 3 different rates of static load were subjected on them by using Universal Testing Machine (UTM). These three different rates were 0.01kN/s (Low rate), 0.2 kN/s (Medium rate) and 15kN/s (High rate). (Unit Test Scientific Sdn Bhd 2008).

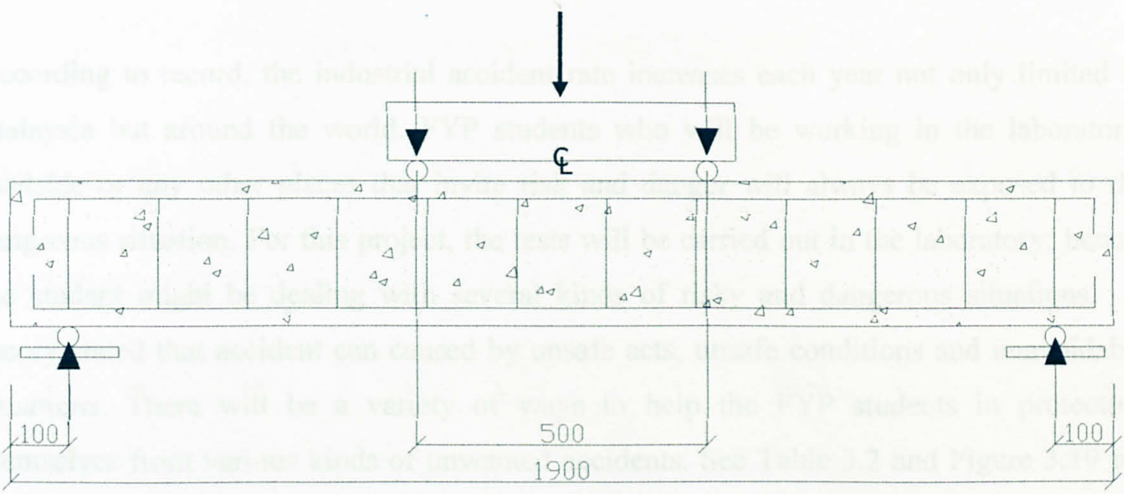


Figure 3.17: Beam specimens' setup and loading arrangement.

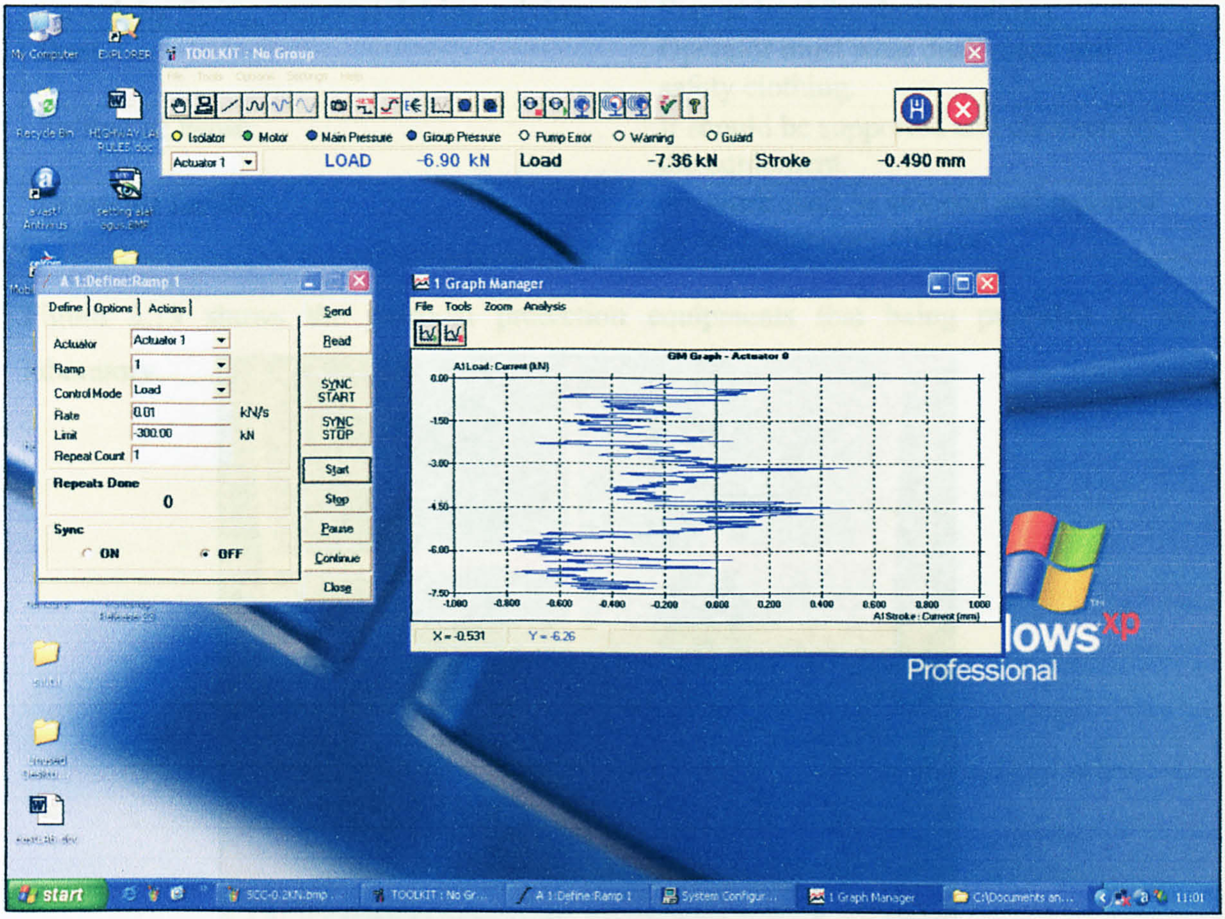


Figure 3.18: Computer software used to generate the results executed from the static load machine (UTM machine)

3.8 HAZARD ANALYSIS

According to record, the industrial accident rate increases each year not only limited in Malaysia but around the world. FYP students who will be working in the laboratory, roadside or any other places that invite risk and danger will always be exposed to the dangerous situation. For this project, the tests will be carried out in the laboratory; hence, the student might be dealing with several kinds of risky and dangerous situations. A theory stated that accident can caused by unsafe acts, unsafe conditions and unavoidable situations. There will be a variety of ways to help the FYP students in protecting themselves from various kinds of unwanted accidents. See Table 3.2 and Figure 3.19 for further hazard analysis.

Table 3.2: Potential hazards and precautions

Hazard	Precautions
Struck by flying material during mixing	Stay at least 2m during mixing.
Dust	Operator must wear dusk mask and safety clothing.
Falling of beam	It should be supported and clamped by the equipment.
Beam hit facility	the work shall be stopped and reported to the Laboratory Officer

Figure 3.19 shows the personal protection equipments that being provided at the laboratory.

Figure 3.19: Personal protection equipments

CHAPTER 4

RESULTS AND DISCUSSION

4.1 FRESH CONCRETE RESULTS

Table 4.1: Fresh Self-Compacting Concrete Properties Tests

Mix No	V- Funnel (sec)	Slump Flow (mm)		L-Box (mm)		T_{50} (sec)
		0°	90°	H_{max}	H	
1	Test of failed fresh concrete					
2	9	550	590	210	90	5
3	15	770	690	130	90	2
4	2	790	850	100	90	2
5	2	820	910	100	100	2

Table 4.2: Requirement for high strength SCC

Testing Item	Unit	Spec
Slump Flow	mm	600-650mm
Flow time until 500mm (T_{50})	Sec	3-50
V type funnel flow time	sec	8-15

According to Table 4.1, we can deduce that mix 3, 4, and 5 did not satisfy the condition for T_{50} flow time and V-Funnel time. ***MIX 2*** can be considered as the optimum mix design because it showed the closest result to Table 4.2 which shows the requirement values for high strength of SCC (G. De Schutter 2005):

- The values for the Slump Flow were 590mm (90°) and 550mm (0°) which were the closest values to the standard requirement (See Table 4.2) for SCC to be regarded as high strength.
- The flow time until 500mm spreading, T_{50} was 5 seconds which satisfied the requirement in Table 4.2.
- V funnel time is 9 sec, satisfied the condition in Table 4.2.

Test of fresh SCC for mix design No.1 failed because it was too dry and did not flow at all due to the lack of water proportion which caused the causes passing ability of that concrete mixture out of range.

4.2 HARDENED CONCRETE TEST RESULTS

Table 4.3: Results on Hardened Concrete Test for SCC

Mix No.	*Stress/ Compressive strength (MPa)				*Maximum Loading (kN)				*Weight of cube (kg)			
	1d	3d	7d	28d	1d	3d	7d	28d	1d	3d	7d	28d
1	No test conducted due to fail in fresh concrete test											
2	**32.92**	**47.71**	**62.51**	**64.90**	**329.2**	**477.1**	**625.1**	**649.0**	**2.457**	**2.482**	**2.579**	**2.506**
3	**16.71**	**28.49**	**52.05**	**59.75**	**167.1**	**284.9**	**520.5**	**597.5**	**2.264**	**2.407**	**2.462**	**2.573**
4	**25.77**	**38.45**	**42.66**	**53.57**	**257.7**	**384.5**	**426.6**	**535.7**	**2.414**	**2.432**	**2.427**	**2.454**
5	**25.40**	**38.48**	**44.75**	**59.79**	**254.0**	**384.8**	**447.5**	**597.9**	**2.406**	**2.419**	**2.503**	**2.407**

*Average values

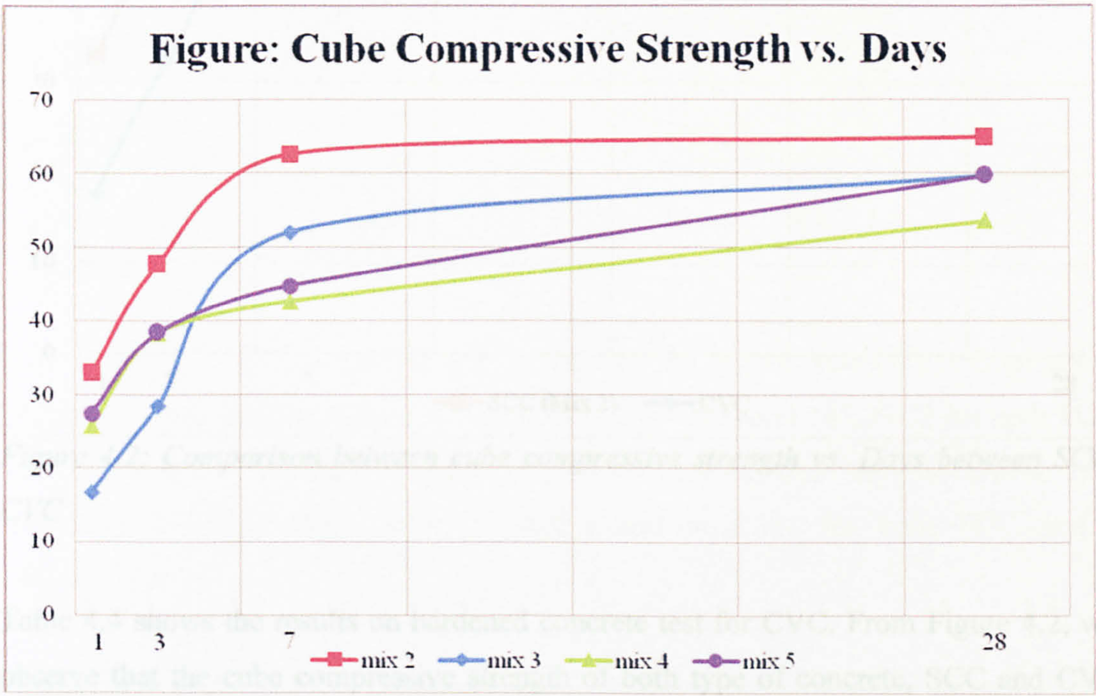


Figure 4.1: Cube Compressive Strength Vs. Days for 4 different types of SCC mix

Minimum requirement for SCC compressive strength is 50MPa in 28days. All mixes satisfied the requirement but ***MIX 2*** obtained the best result as it gives the highest value of failure loading and compressive strength. This value was used in the SCC beam design as the optimum mix design.

Table 4.4: Results on Hardened Concrete Test for CVC

Day	Stress
1	17.7
3	32.3
7	50.7
28	62.16

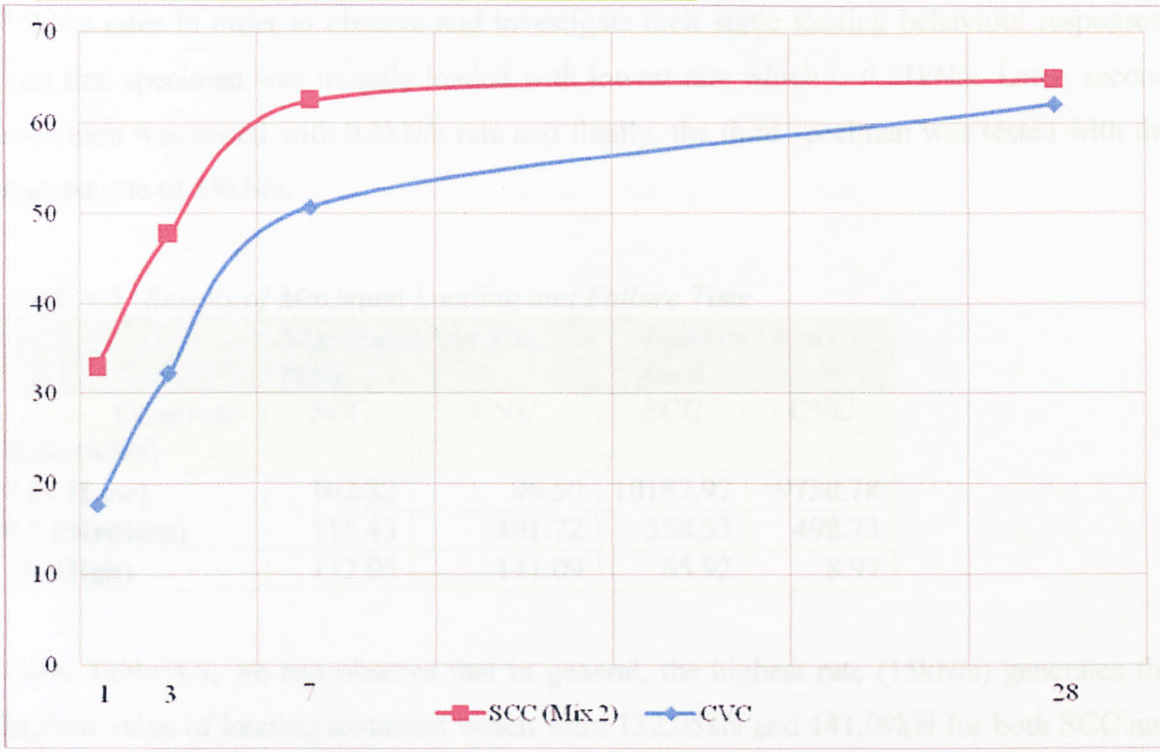


Figure 4.2: Comparison between cube compressive strength vs. Days between SCC and CVC

Table 4.4 shows the results on hardened concrete test for CVC. From Figure 4.2, we can observe that the cube compressive strength of both type of concrete, SCC and CVC are having almost similar strength with the 28 days result for SCC is 64.90 MPa and while, for CVC is 62.16MPa. Thus, both selected CVC and SCC mix proportions were used to cast the beam specimens for the static load test. This total of two mixes was used to cast experimental beams: one CVC mixture and another one is SCC mixture, where mix 2 was chosen from all 5 different mix proportions. The water-to-cementitious materials ratio were kept constant at 0.4 for CVC, while for SCC is 0.35 in order to achieve similar compressive strength.

4.3 STATIC LOADING TESTS RESULTS

4.3.1 Maximum Load and Failure Time

Static compressive tests were performed by loading the specimens at three different rates. All the beam specimens of both, SCC and CVC were loaded with 0.01kN/s, 0.2k/Ns and 15kN/s rates in order to observe and investigate their static loading behaviour responses. The first specimen was initially loaded with lowest rate which is 0.01kN/s. Later, second specimen was tested with 0.2kN/s rate and finally, the third specimen was tested with the highest rate of 15kN/s.

Table 4.5: Results of Maximum Loading and Failure Time

	Maximum Loading (kN)		Failure Time (sec)	
Concrete / Rate (kN/s)	SCC	CVC	SCC	CVC
0.01 (Low)	102.82	96.50	10182.97	9720.78
0.2 (Medium)	111.43	101.72	558.53	498.73
15 (High)	132.05	141.09	65.92	8.97

From Table 4.5, we can observe that in general, the highest rate (15kN/s) generates the highest value of loading sustained which were 132.05kN and 141.09kN for both SCC and CVC respectively. While the lowest rate of 0.01kN/s contributed the lowest value of maximum loadings which were 102.82kN and 96.50kN for both SCC and CVC respectively.

Failure time taken also can be considered as another element to compare and analyse the results. The lowest rate of 0.01kN/s generated longer times which were 10182.97 sec (2 hrs 49mins) for SCC and 9720.78 sec (2hrs 42 mins) for CVC. The higher rate of 15kN/s gave shorter period of time to exhibit the maximum failure loadings. Even though, maximum loadings for highest value of rate (15kN/s) were higher as compared to the lower values, but they also generate the shorter period of time to fail. Hence, we cannot say that highest value of rate can generate better result; it is safer to stick with medium rate of load applied.

Overall, SCC gave better result as compared to CVC results as it obtained higher value of maximum loadings and also, they take longer period of time to fail.

4.3.2 Comparison of Relationship between Rates with Maximum Loading / Failure Time

Table 4.6: The Relationship between Rate and Maximum Loading/Failure Time

Increment in rate	Increment in Maximum Loading		Changing in Failure Time per 1 unit of changing in Rate	
	SCC	CVC	SCC	CVC
20	1.084	1.054	-481.22	-461.1
75	1.185	1.387	-6.57	-6.53
1500	1.2843	1.462	-6.74	-6.47

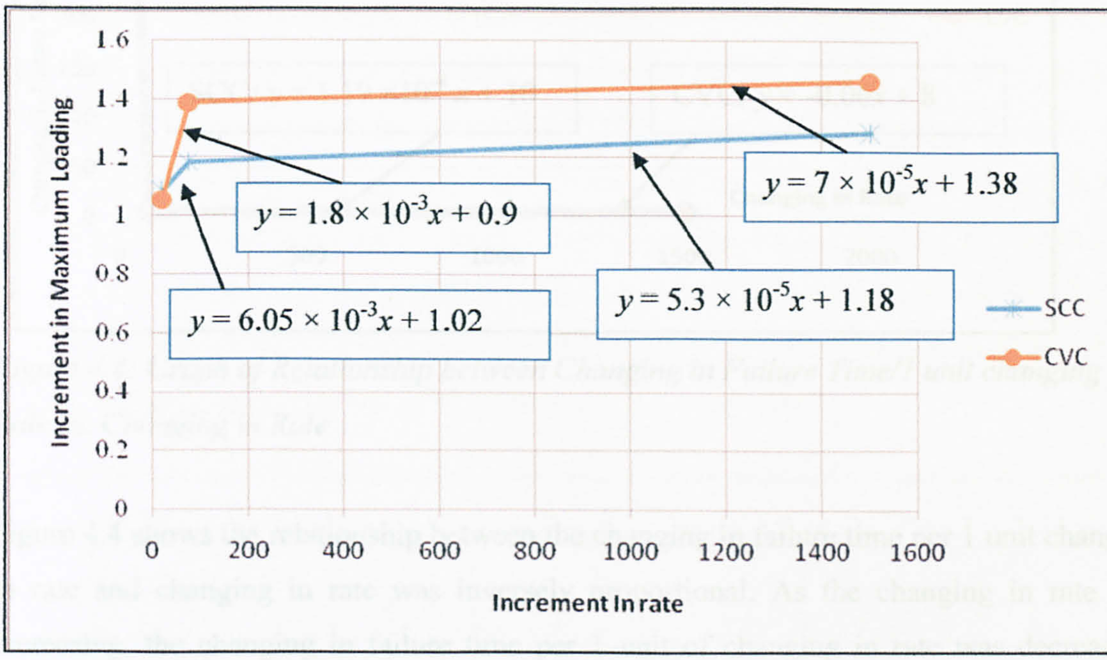


Figure 4.3: Graph of Relationship between the Increment of Rate and Maximum Loading

Table 4.6 shows the relationship between values of increment in rate with values of increment in maximum loading and failure time. From Figure 4.3, it can be described that the relationship between increment in rate and increment in maximum loading was proportional as the increasing in increment value of rate gave the increasing value of increment in maximum loading. During the 20 times of increment value in rate, CVC gave the lower value of maximum loading increment than SCC. But during the increment in rate of 75 times and 1500 times, the values for increment in maximum loadings for CVC were higher than SCC.

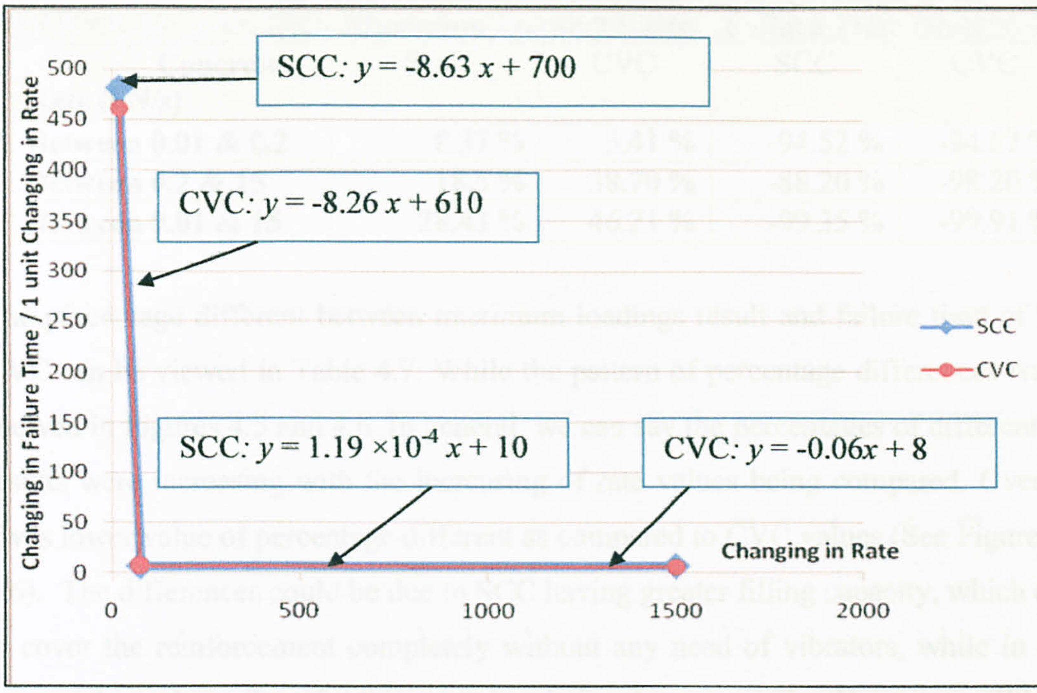


Figure 4.4: Graph of Relationship between Changing in Failure Time/1 unit changing in Rate vs. Changing in Rate

Figure 4.4 shows the relationship between the changing in failure time per 1 unit changing in rate and changing in rate was inversely proportional. As the changing in rate was increasing, the changing in failure time per 1 unit of changing in rate was decreasing. From this figure, it can be observed that the changing of failure time per 1unit of changing in rate was consistent when the changing in rate was more than 20 times with the ranging of 6.5 to 6.8 for SCC and 6.4 to 6.6 for CVC. Overall, it can be said that SCC generated higher values of decreasing in changing failure time per 1unit changing in rate. The pattern of the graph only consistent after the 20times of increment in rate occurred.

Table 4.7: Results of Percentage Differences on Time and Failure Loading Basis

Rate (kN/s) \ Concrete	Percentage Differences (%) Maximum Loading Basis SCC	Maximum Loading Basis CVC	Failure Time Basis SCC	Failure Time Basis CVC
Between 0.01 & 0.2	8.37 %	5.41 %	-94.52 %	-94.87 %
Between 0.2 & 15	18.5 %	38.70 %	-88.20 %	-98.20 %
Between 0.01 & 15	28.43 %	46.21 %	-99.35 %	-99.91 %

The percentage different between maximum loadings result and failure time of SCC and CVC can be viewed in Table 4.7. While the pattern of percentage differences was clearly showed in Figures 4.5 and 4.6. In general, we can say the percentages of different between results were increasing with the increasing of rate values being compared. Overall, SCC gives lower value of percentage different as compared to CVC values (See Figures 4.5 and 4.6). The differences could be due to SCC having greater filling capacity, which enables it to cover the reinforcement completely without any need of vibrators, while in CVC the process depends on the vibration treatment being done correctly. The greater filling ability of SCC reduces the occurrence of voids between steel and concrete.

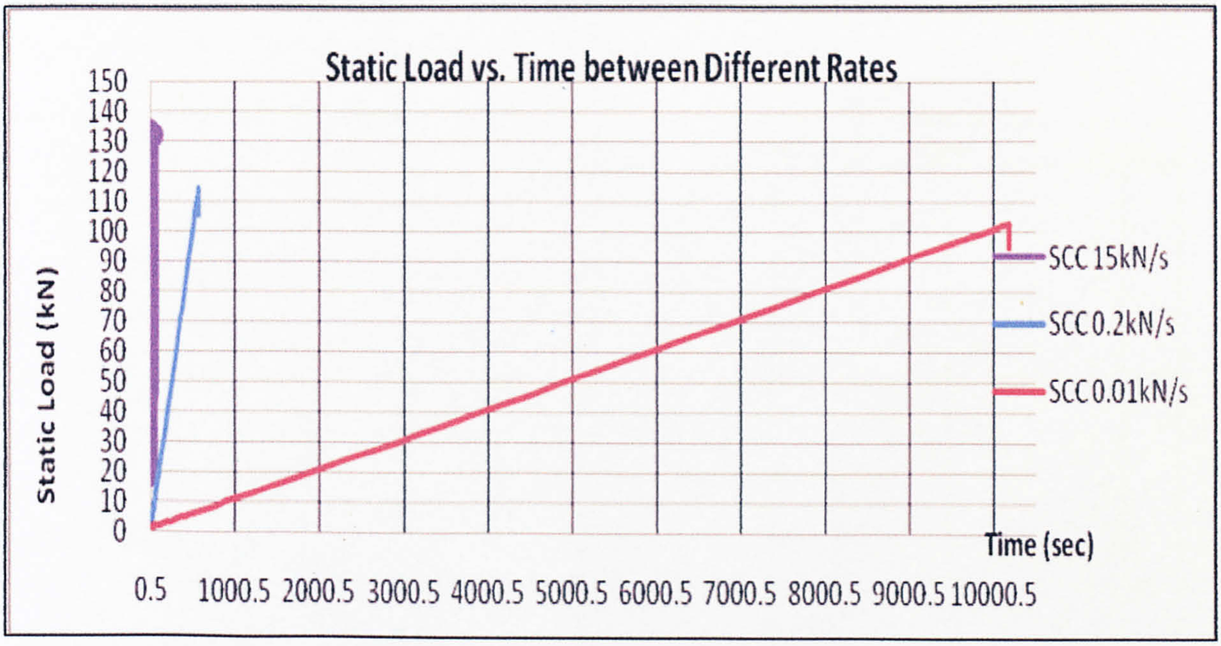


Figure 4.5: Graph of Static Load vs. Time between different rates of SCC

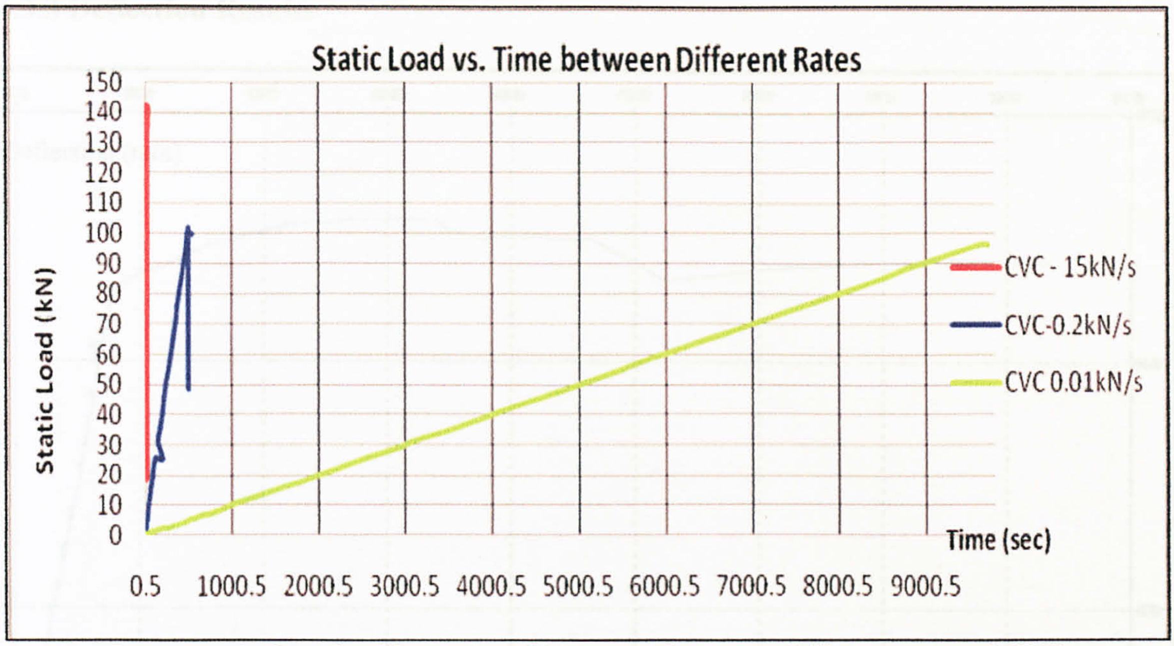


Figure 4.6: Graph of Static Load Vs. Time between different rates of CVC

4.3.3 Deflection Results

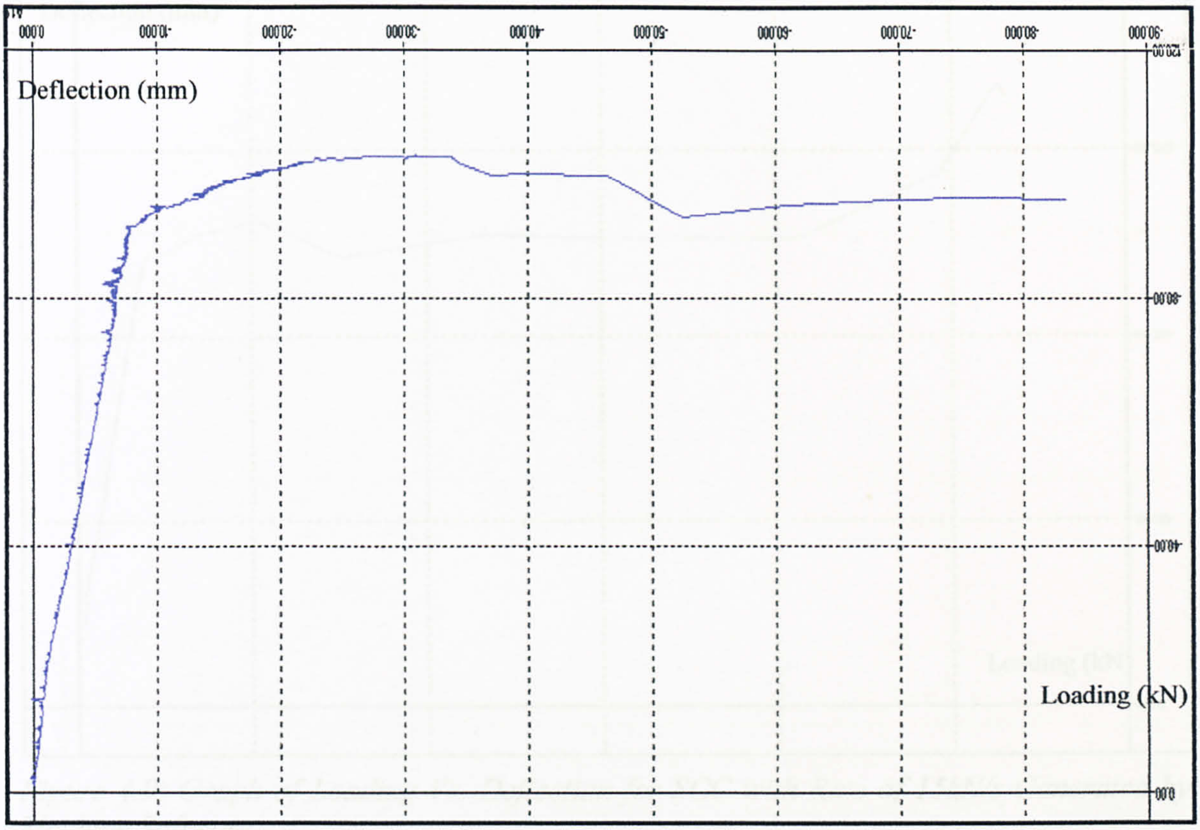


Figure 4.7: Graph of Loading Vs. Deflection for SCC with Rate of 0.01kN/s Generated by Machine Software

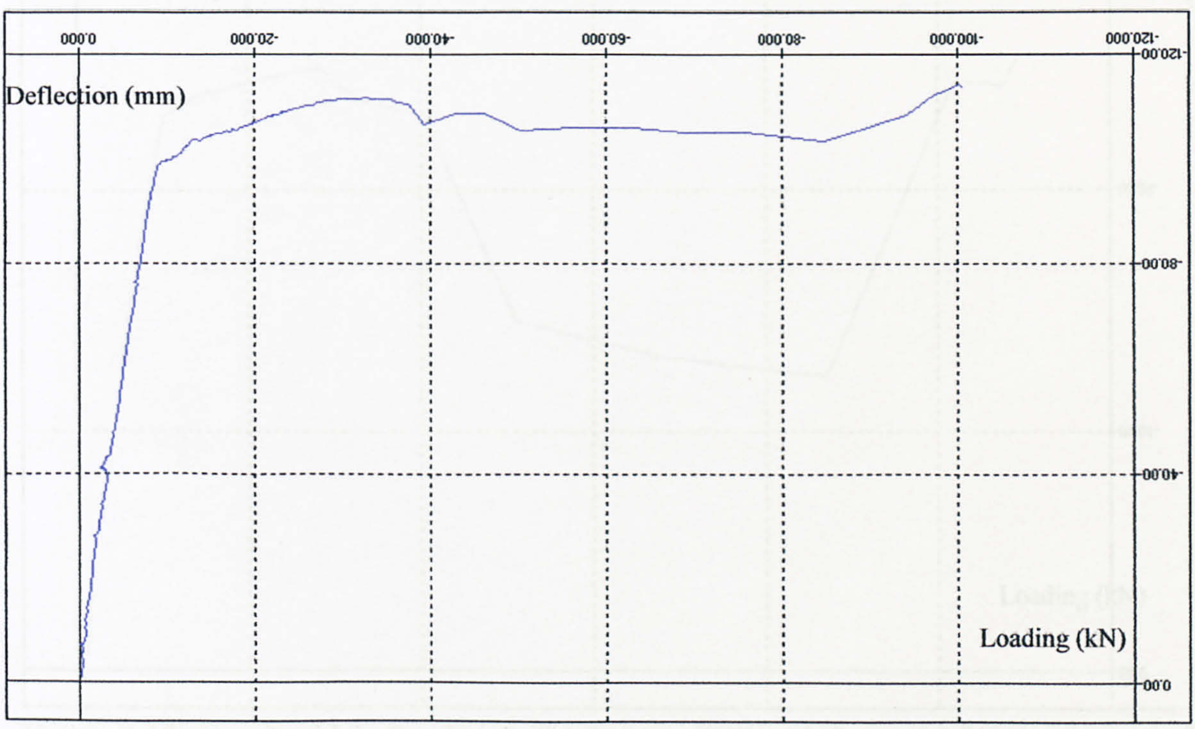


Figure 4.8: Graph of Loading Vs. Deflection for SCC with Rate of 0.2kN/s Generated by Machine Software

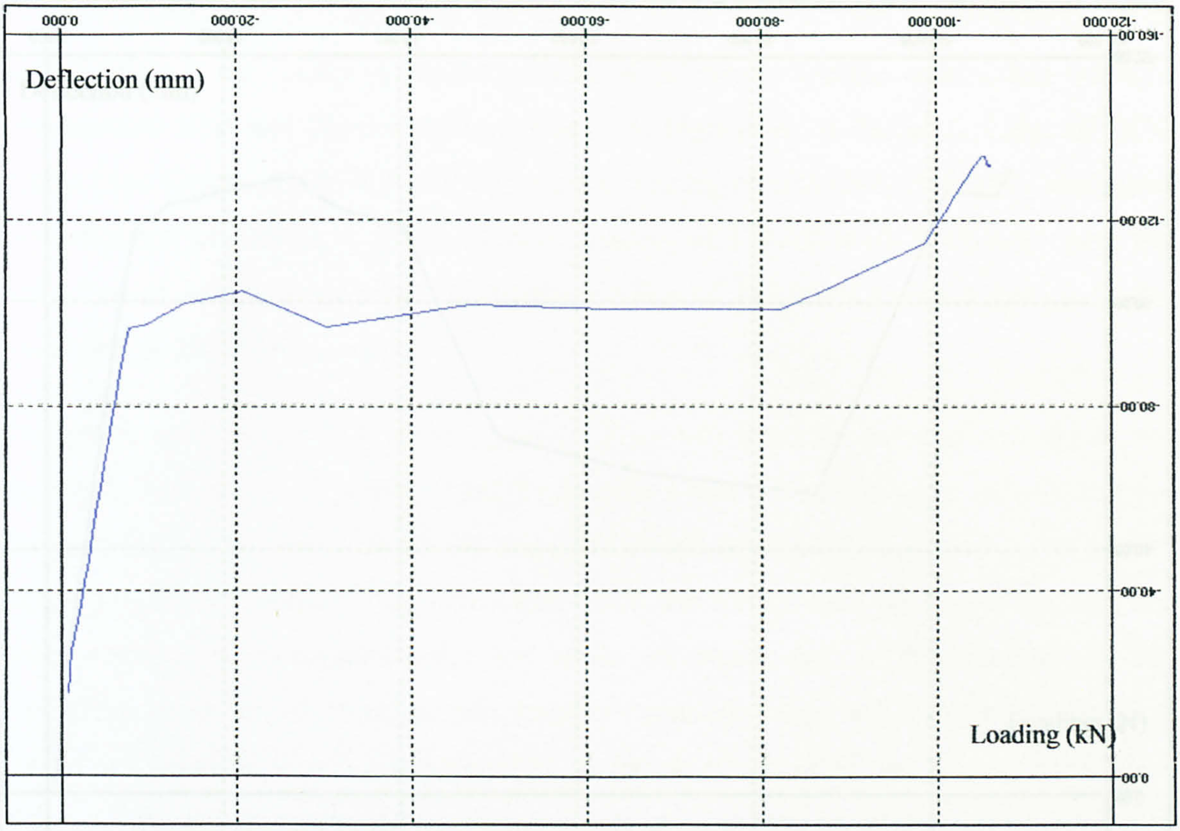


Figure 4.9: Graph of Loading Vs. Deflection for SCC with Rate of 15kN/s Generated by Machine Software

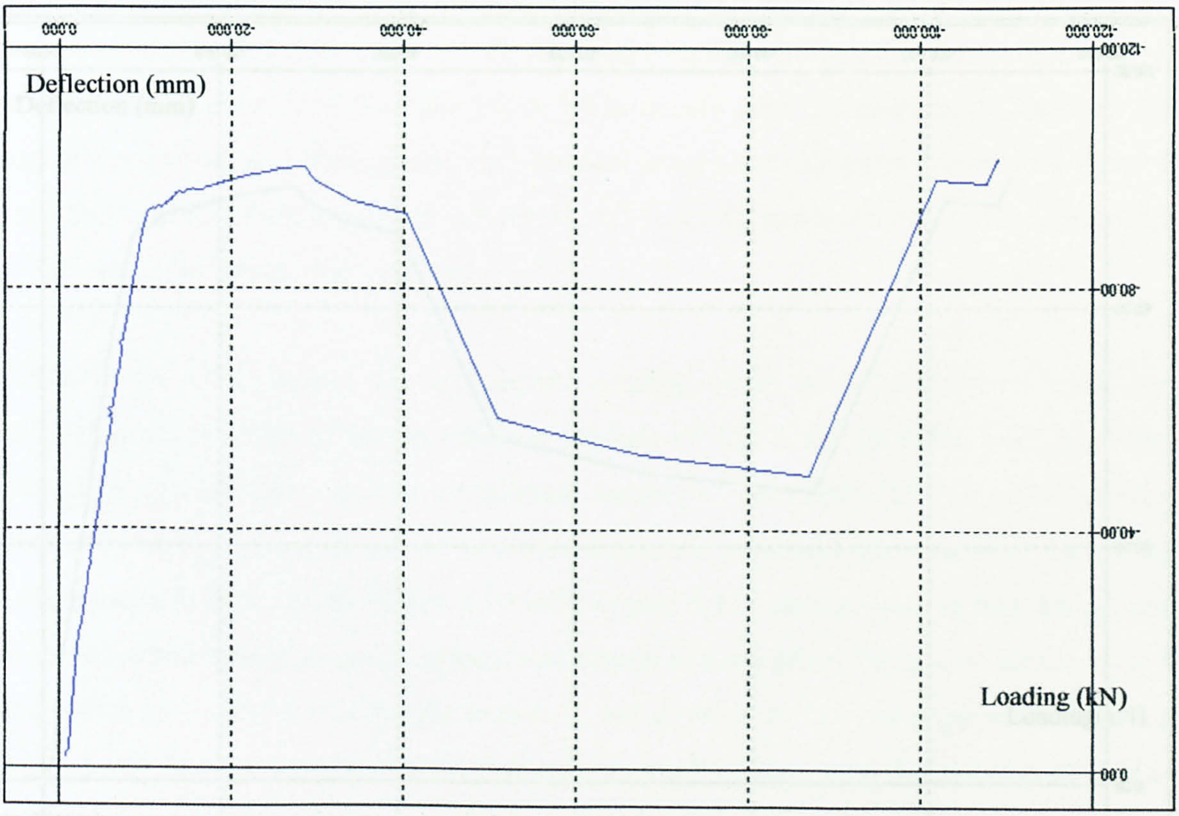


Figure 4.10: Graph of Loading Vs. Deflection for CVC with Rate of 0.01kN/s Generated by Machine Software

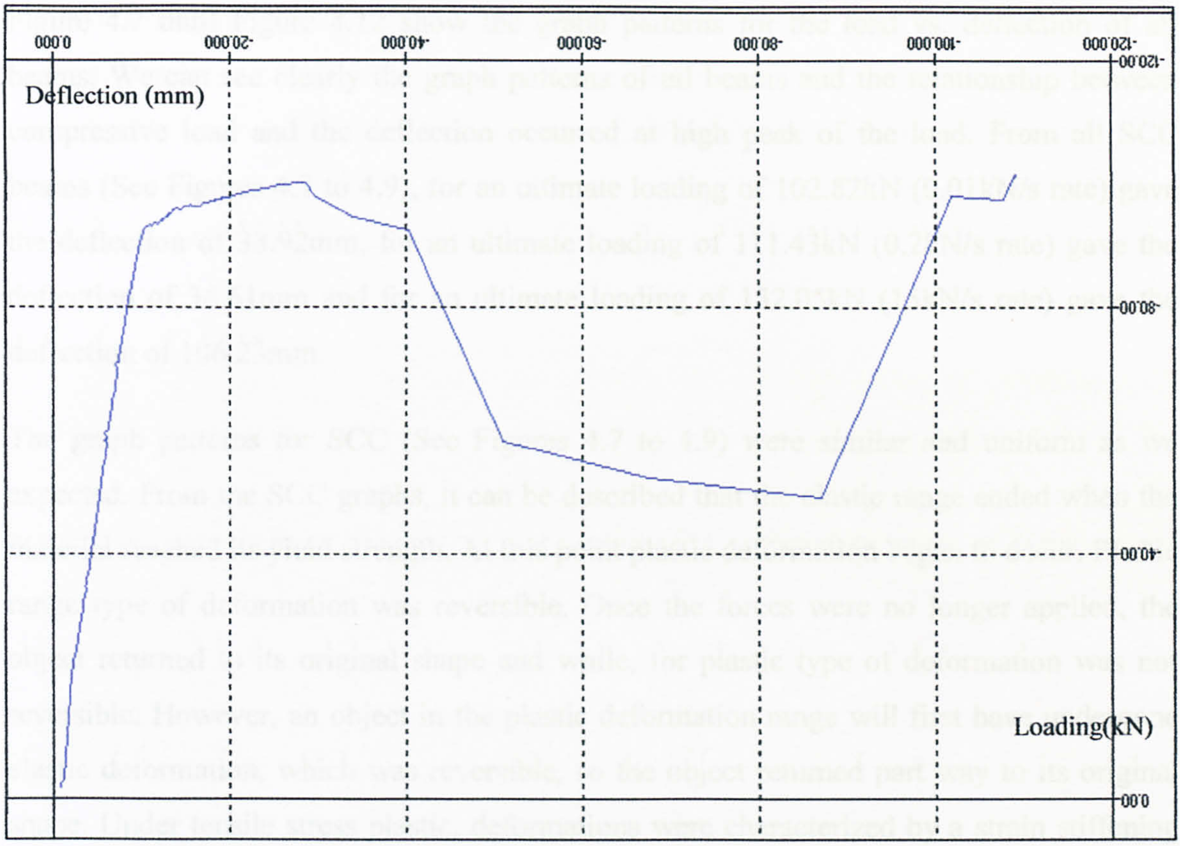


Figure 4.11: Graph of Loading Vs. Deflection for CVC with Rate of 0.2kN/s Generated by Machine Software

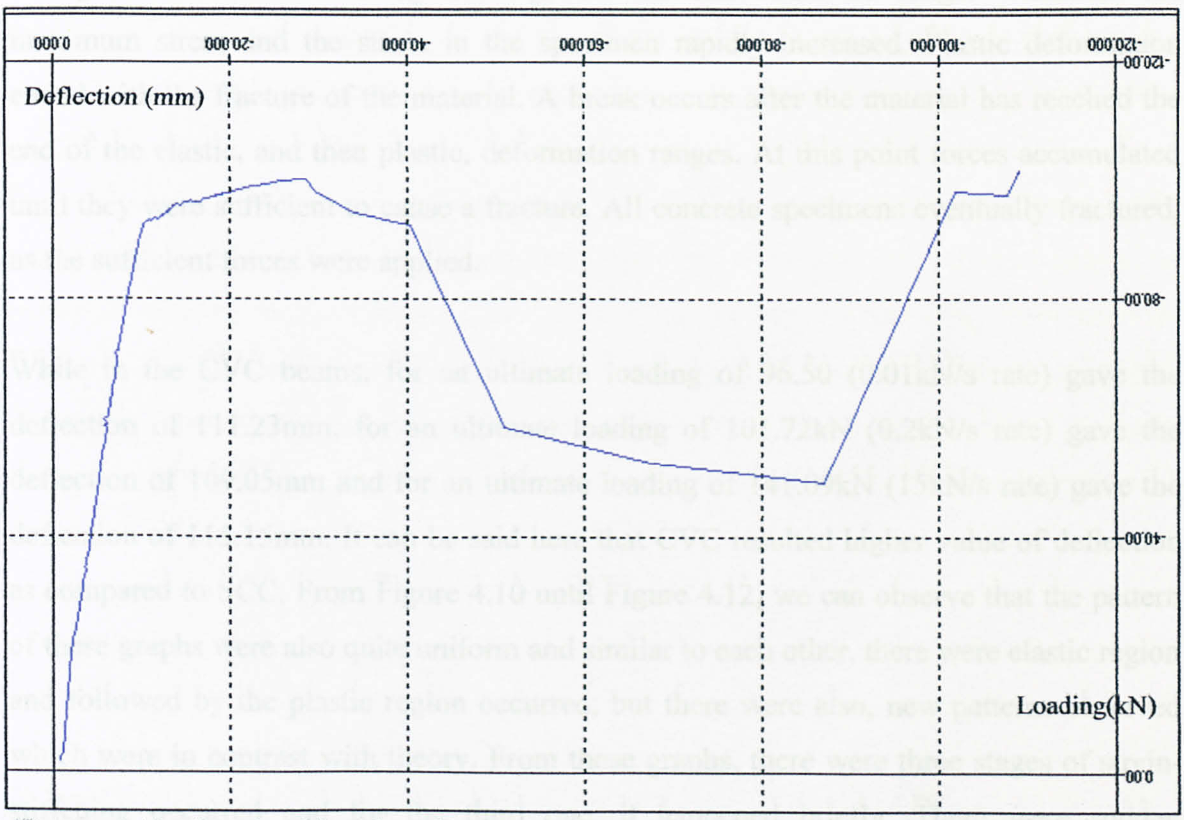


Figure 4.12: Graph of Loading Vs. Deflection for CVC with Rate of 15kN/s Generated by Machine Software

Figure 4.7 until Figure 4.12 show the graph patterns for the load vs. deflection of all beams. We can see clearly the graph patterns of all beams and the relationship between compressive load and the deflection occurred at high peak of the load. From all SCC beams (See Figures 4.7 to 4.9), for an ultimate loading of 102.82kN (0.01kN/s rate) gave the deflection of 33.92mm, for an ultimate loading of 111.43kN (0.2kN/s rate) gave the deflection of 34.61mm and for an ultimate loading of 132.05kN (15kN/s rate) gave the deflection of 106.23mm.

The graph patterns for SCC (See Figures 4.7 to 4.9) were similar and uniform as we expected. From the SCC graphs, it can be described that the elastic range ended when the material reached its yield strength. At this point plastic deformation began to occur. Elastic range type of deformation was reversible. Once the forces were no longer applied, the object returned to its original shape and while, for plastic type of deformation was not reversible. However, an object in the plastic deformation range will first have undergone elastic deformation, which was reversible, so the object returned part way to its original shape. Under tensile stress plastic, deformations were characterized by a strain stiffening region and a necking region and finally, fracture. Necking began after the Ultimate Strength was reached. During necking, the material could no longer withstand the maximum stress and the strain in the specimen rapidly increased. Plastic deformation ended with the fracture of the material. A break occurs after the material has reached the end of the elastic, and then plastic, deformation ranges. At this point forces accumulated until they were sufficient to cause a fracture. All concrete specimens eventually fractured, as the sufficient forces were applied.

While in the CVC beams, for an ultimate loading of 96.50 (0.01kN/s rate) gave the deflection of 111.23mm, for an ultimate loading of 101.72kN (0.2kN/s rate) gave the deflection of 109.05mm and for an ultimate loading of 141.09kN (15kN/s rate) gave the deflection of 115.15mm. It can be said here that CVC resulted higher value of deflection as compared to SCC. From Figure 4.10 until Figure 4.12, we can observe that the pattern of these graphs were also quite uniform and similar to each other, there were elastic region and followed by the plastic region occurred, but there were also, new patterns observed which were in contrast with theory. From these graphs, there were three stages of strain-stiffening occurred and for the third one, it happened briefly. There were sudden decrement and increment between second strain-stiffening. These sudden decrement and increment caused the contrast with the theory. The reasons may revolve around the materials performance or many other reasons that need further clarification. Hence, it needed more study and analysis to find the possible reasons behind this phenomenon.

4.3.4 Crack Patterns / Propagations

Table 4.8: The Summarized Results of Crack Pattern/Propagations

Type of Concrete	Total Applied Load (kN)			No. of Crack	Max. Crack Width (mm)	Max. Crack Hgt. (mm)	Angle of Failure Diagonal Crack (°)
	At 1st Flexural Mark Crack (kN)	At 1st Diagonal Mark Crack (kN)	Max. Load Marking (kN)				
SCC 0.01kN/s	50	70	100	13	230	10	55
SCC 0.2kN/s	30	70	100	13	250	90	60
SCC 15kN/s	Nil.	Nil.	Nil.	9	220	25	65
CVC 0.01kN/s	20	50	90	14	250	15	45
CVC 0.2kN/s	30	50	80	10	240	3	55
CVC 15kN/s	Nil.	Nil.	Nil.	12	240	110	60

Figure 4.14 shows typical pictures of all beams subjected to static load and their failure moment. The cracks were outlined with a red felt tip marker and the crack width was determined and the load applied during the cracks occurred were labelled at each loading stage. The summarized results of crack pattern/propagation can be observed in Table 4.8.

Figure 4.13 shows the crack patterns of SCC and CVC beams at failure. During early stages of loading, fine vertical flexural crack appeared around the mid span of beams, as expected. With the increase in load, new flexural cracks were formed away from the mid-span area. With further increase in load, those flexural cracks started to propagate diagonally towards the loading point and other new diagonal cracks began to form separately in locations farther away from the mid-span along the beam. (See Figures 4.13 & 4.14).

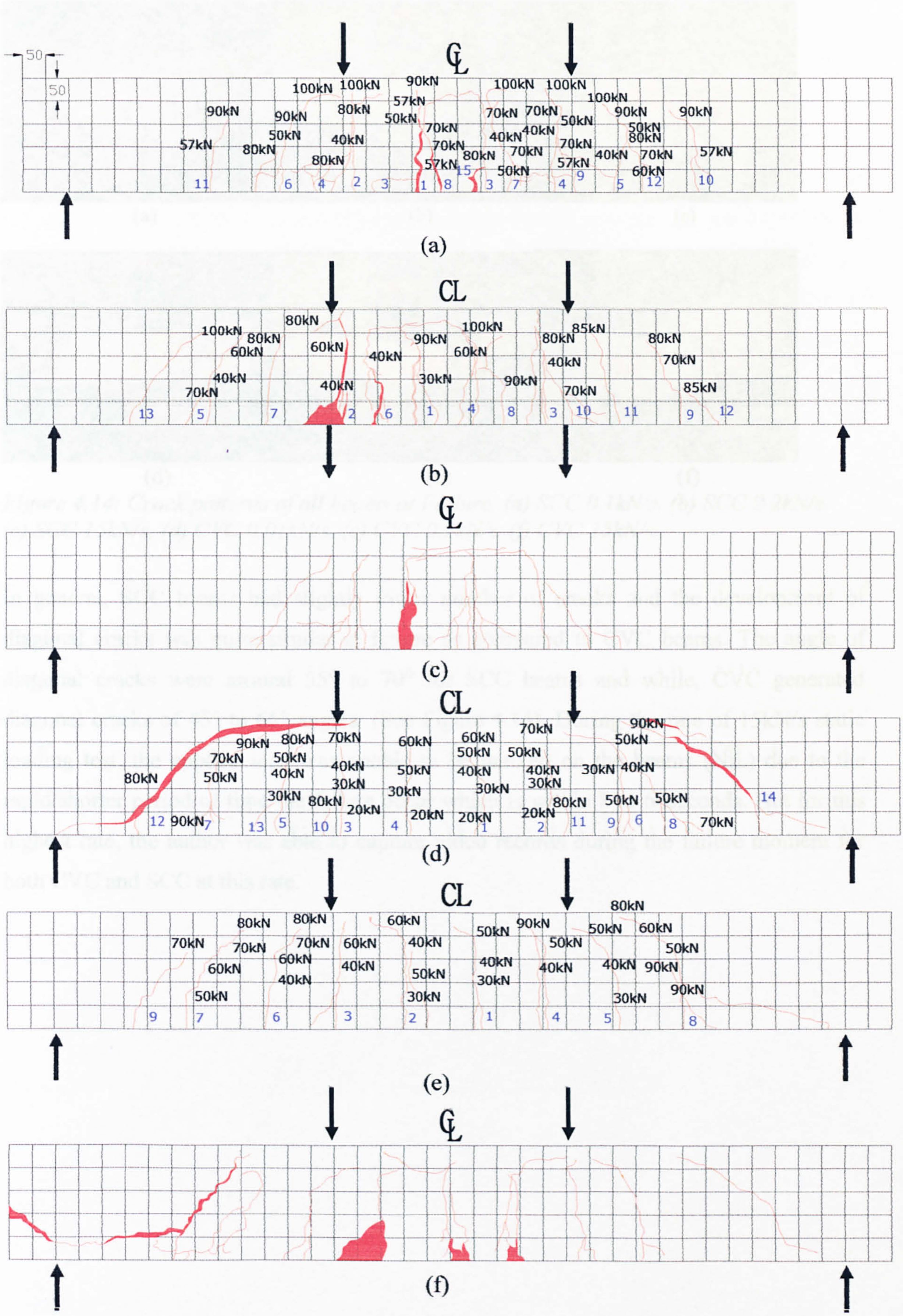
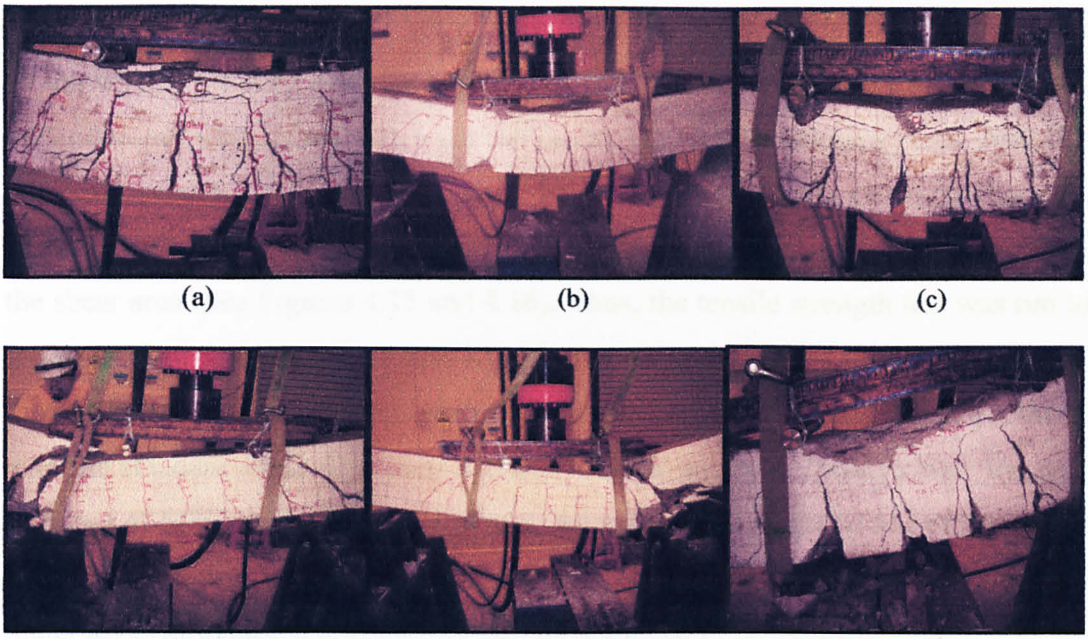


Figure 4.13: Crack pattern for all beams. (a) SCC 0.01kN/s. (b) SCC 0.2kN/s. (c) SCC 15kN/s. (d) CVC 0.01kN/s. (e) CVC 0.2kN/s. (f) CVC 15kN/s



(a) (b) (c)

(d) (e) (f)

Figure 4.14: Crack patterns of all beams at Failure. (a) SCC 0.1kN/s. (b) SCC 0.2kN/s. (c) SCC 15kN/s. (d) CVC 0.01kN/s. (e) CVC 0.2kN/s. (f) CVC 15kN/s.

In general, SCC beams had slightly lower number of cracks and the development of diagonal cracks was quite similar at failure as compared to CVC beams. The angle of diagonal cracks were around 55° to 70° for SCC beams and while, CVC generated diagonal cracks of 45° to 65° angles. (See Figure 4.14). During the rate of 15kN/s static loading test, the applied load was unable to be marked on the beams (Nil.) due to the rapid/shorter period of time the failure occur which is within 8 to 60seconds. But for this highest rate, the author was able to capture video records during the failure moment for both CVC and SCC at this rate.

From the observation on CVC beams after 0.01kN/s and 0.2kN/s rate of static load applied on the beams, it can be said that both beams of CVC tend to generate shear failure. Hence, the additional analysis and test were run on the matter to investigate what were the causes due to the reason that the design of these beams supposedly only generates flexural failure. From the physical observation on CVC 0.01kN/s beam, there was link failure occurred at the shear area (See Figures 4.15 and 4.16). Thus, the tensile strength test was run to check the strength of link material. Table 4.9 shows the result of link's tensile strength test. From the result, it was found that the average value of link's tensile strength is 115.4MPa, lower than the standard value of tensile strength for link which is 250MPa with the percentage different of 54% which is half of the standard value. This might be one of the good reasons that the link failed and shear failure occurred. Hence, this proved that for acceptance, the material performance is absolutely essential and need to be assured.

Table 4.9: The Results of Tensile Strength Test on Link Bar Material.

Sample	Weight(g)	Yield (mm)	Tensile Strength (MPa)
Link 1	140.55	3.27	92.68
Link 2	142.55	2.62	126.28
Link 3	142.52	3.57	115.67
Average Tensile Strength (MPa)			115.4

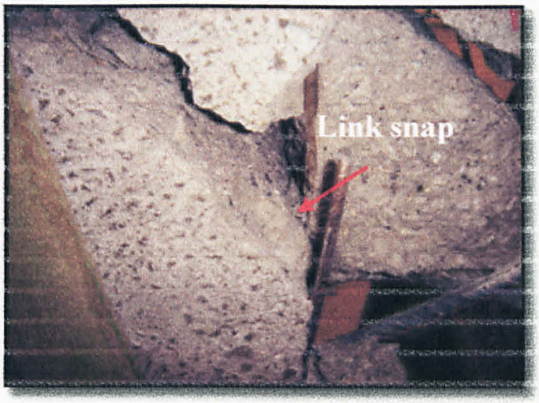


Figure 4.15: The link failure occurred

Figure 4.16: The UTM machine used for the tensile strength test of Link Bar

CHAPTER 5
CONCLUSION

5.1 CONCLUSION

This project presented the results of a research study on the **Comparison of Static Response of Self-compacting Concrete (SCC) and Conventional Vibrated Concrete (CVC).** From the tests that have been carried out, it was found that SCC flexural capacity which were little superior to CVC. The development process of both concrete (SCC and CVC) at 28 days strength were at least 60MPa. Based on the results presented in this project, it can be concluded that:

- The result of static load test for medium rate (0.2kN/s) of SCC gave higher value of maximum loading which was 114.43 kN and for CVC, it gave the value of 101.72kN.
- The rate of load applied also play vital roles as it gave different value of maximum loads and the failures occurred at different time, which the higher increment in rate generated the higher increment of maximum loading and the higher of decrement in failure time.
- For deflection result, both SCC and CVC generated the similar and uniform graphs according to their type. From the observation, it can be seen that SCC generated lower value of deflection as compared to CVC. The graph patterns for SCC resulted as expected and while for CVC, there were new pattern observed which needed further analysis and clarification.
- SCC beams had slightly lower number of cracks and the development of diagonal cracks was quite similar at failure as compared to CVC beams.

5.2 RECOMMENDATION

For recommendation, it is significant to ensure all the materials performance is in excellent condition. As for example, during this project a shear failure occurred (link failure) at 0.01kN/s rate for CVC beam which was supposedly not happen as the design of the beam concentrated on flexural behaviour (shallow beam) only.

For the deflection results analysis, there were sudden decrement and increment occurred between second strain-hardening for all of CVC graph patterns. These sudden decrement and increment caused in contrast with the theory. The reasons may revolve around the materials performance or many other reasons that need further clarification. Hence, it needed more study and analysis to find the possible reasons behind this phenomenon.

CHAPTER 6
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16. Unit Test Scientific Sdn Bhd 2008. Concrete test machines (AD 150/EL, AD 200/EL, AD 300/EL, AD 400/EL) are tested in accordance to the "*British & International Standard*" and awarded the accreditation *ISO 17025* for Calibration and Testing. Retrieved March 21, 2009, from http://www.unittest.com.my/pdf/12.pdf.

APPENDICES

APPENDIX 1

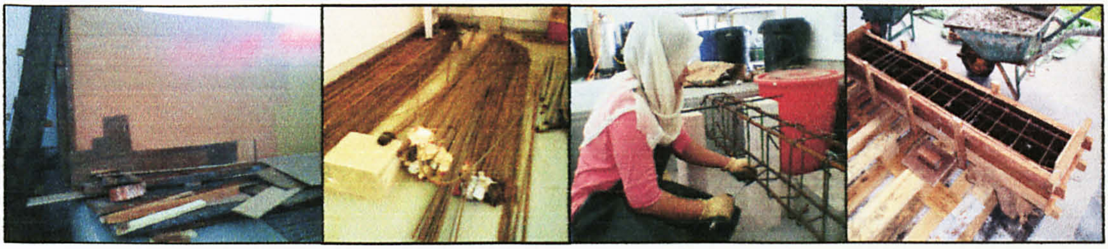
Figures

APPENDIX 1-1

(a) (b) (c) (d)

Figure 1: Preparation of Concrete Materials

(a)Coarse Aggregates (b) Fine Aggregates (c) Ordinary Portland cement (d) Super Plasticizers



(a) (b) (c) (d)

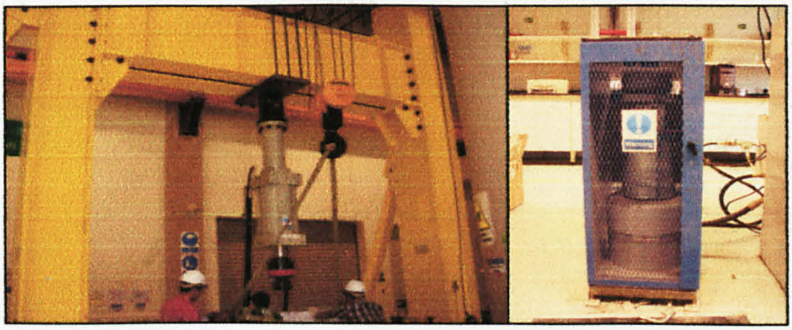
Figure 2: Preparation of Beam Specimens Formwork

(a) Plywood (b) Reinforced bars & links (c) Jointing the bars & links (d) Formwork

(a) (b)

Figure 3: Test Specimens

(a) 150mm × 150mm × 150mm Cube Specimens (b) Beam Specimens



(a) (b)

Figure 4: Machines Used

(a)Universal Testing Machine,Dynamic Machine 500kN (b)Compressive Machine ,ADR 1500

APPENDICES

APPENDIX 1

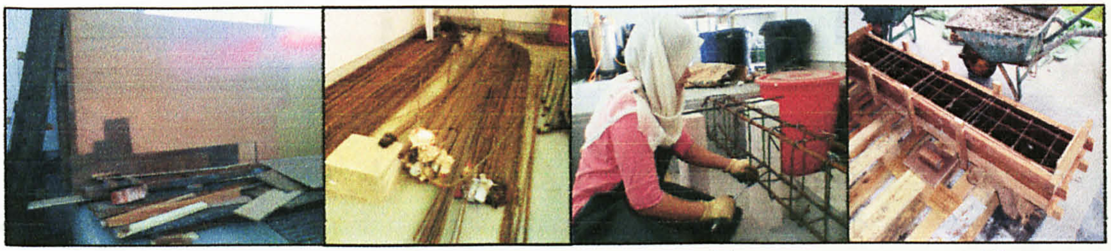
Figures

APPENDIX 1-1

(a) (b) (c) (d)

Figure 1: Preparation of Concrete Materials

(a)Coarse Aggregates (b) Fine Aggregates (c) Ordinary Portland cement (d) Super Plasticizers



(a) (b) (c) (d)

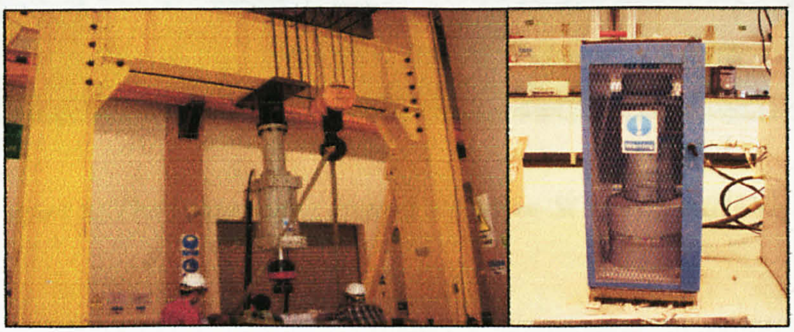
Figure 2: Preparation of Beam Specimens Formwork

(a) Plywood (b) Reinforced bars & links (c) Jointing the bars & links (d) Formwork

(a) (b)

Figure 3: Test Specimens

(a) 150mm × 150mm × 150mm Cube Specimens (b) Beam Specimens

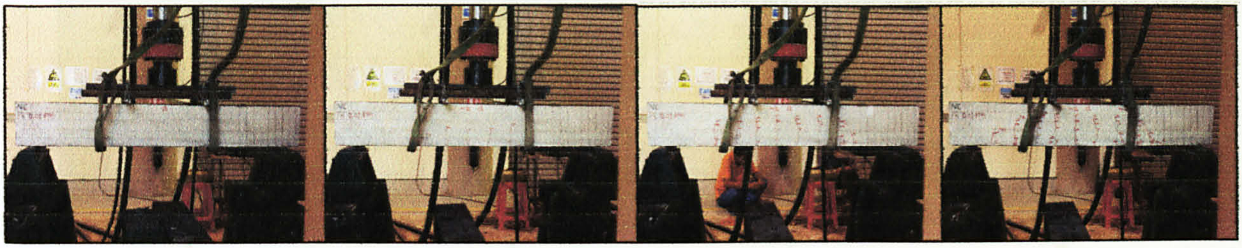


(a) (b)

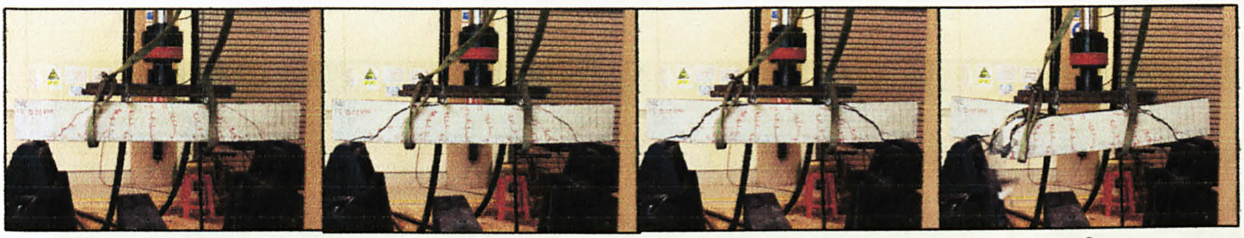
Figure 4: Machines Used

(a)Universal Testing Machine,Dynamic Machine 500kN (b)Compressive Machine ,ADR 1500

APPENDIX 1-2

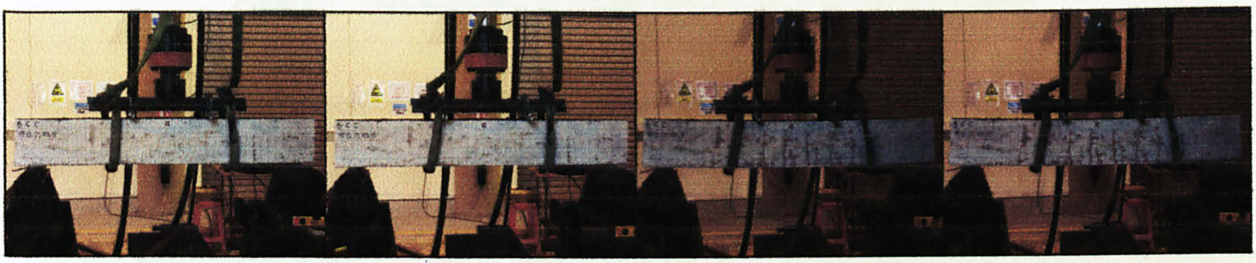


1 *2* *3* *4*



5 *6* *7* *8*

Figure 5: The Sequence of Beam Failure for CVC with 0.01kN/s



1 *2* *3* *4*

5 *6* *7* *8*

Figure 6: The Sequence of Beam Failure for SCC with 0.01kN/s

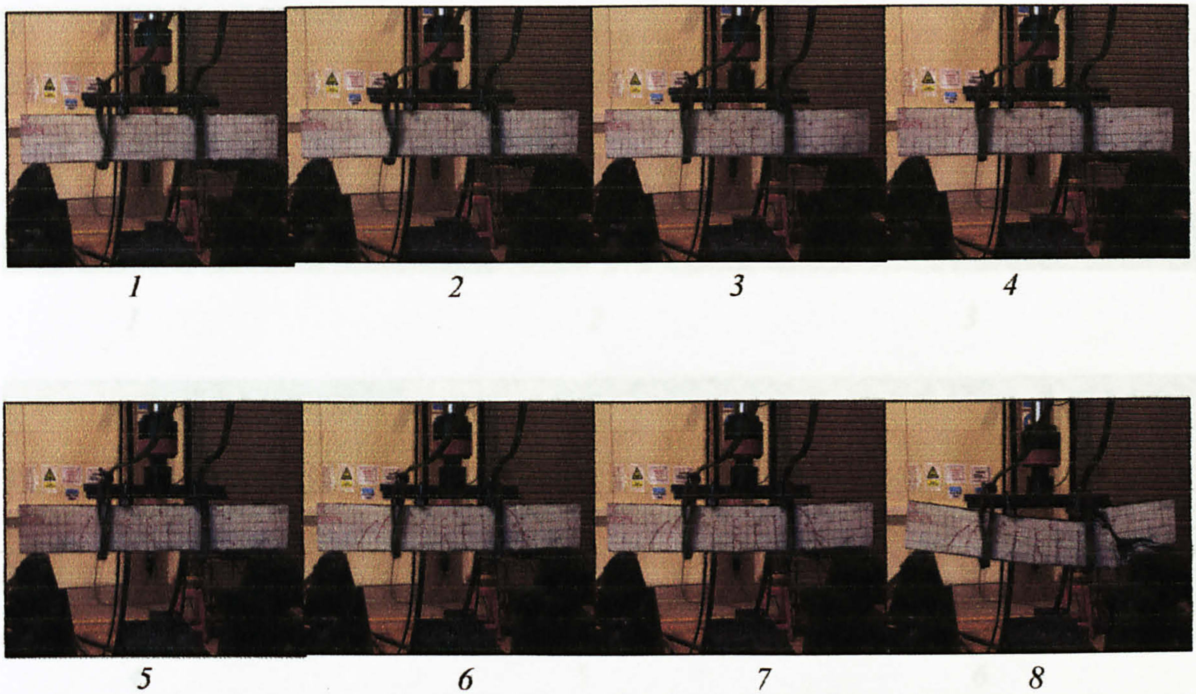


Figure 7: The Sequence of Beam Failure for CVC with 0.02kN/s

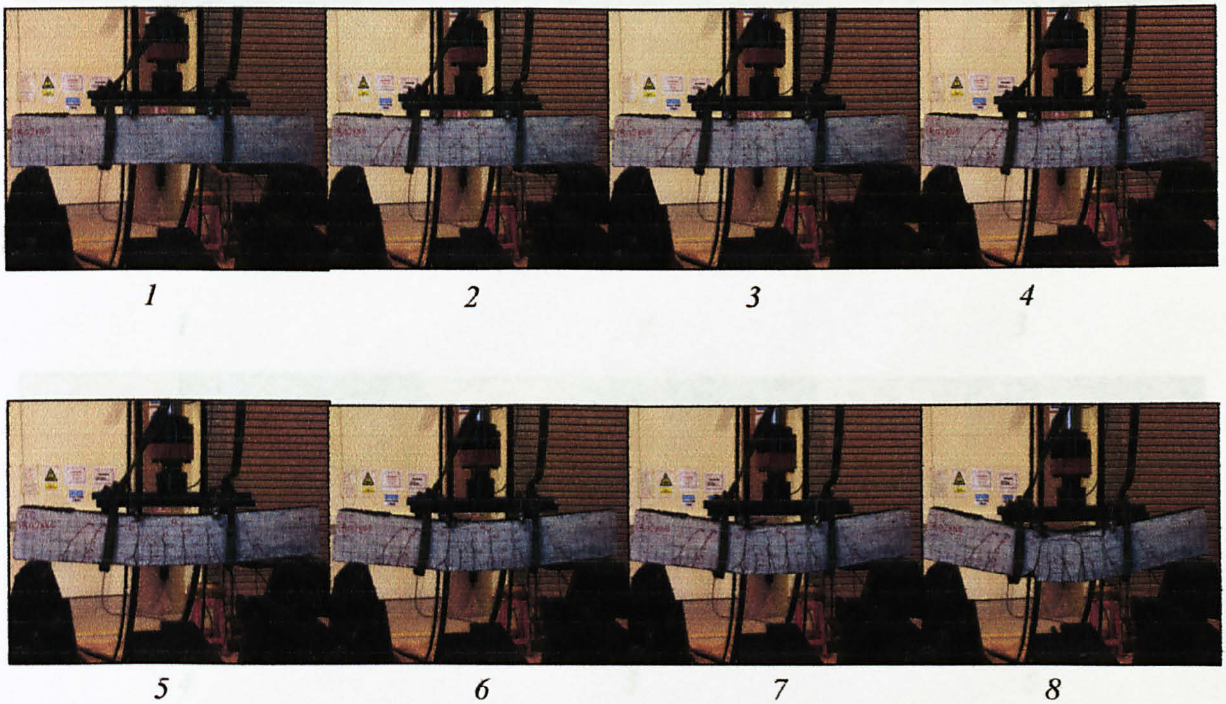
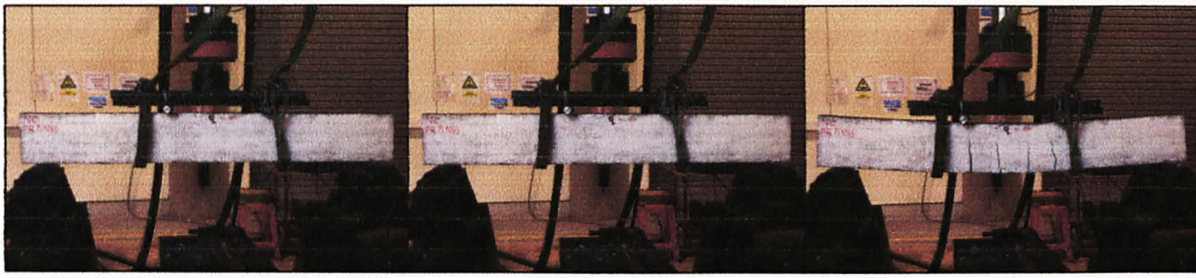


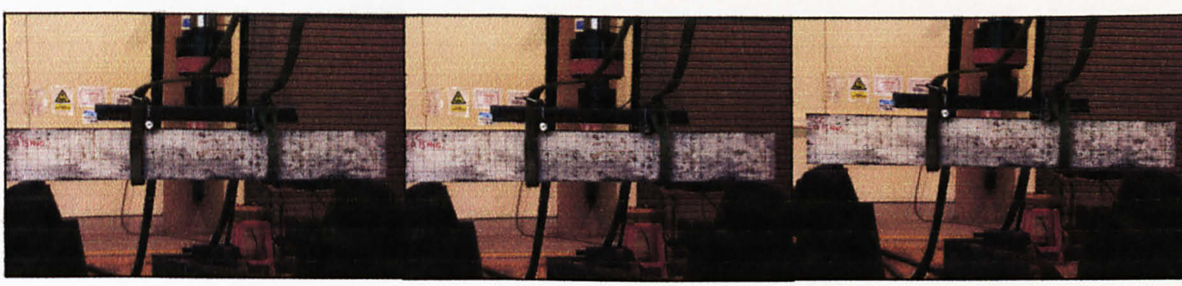
Figure 8: The Sequence of Beam Failure for SCC with 0.02kN/s



1 *2* *3*

4 *5* *6*

Figure 9: The Sequence of Beam Failure for CVC with 15kN/s



1 *2* *3*

4 *5* *6*

Figure 10: The Sequence of Beam Failure for SCC with 15kN/s

APPENDIX 2

Data Generated by Machine and Computer Software

WORKSHOP 3 EXPORTED DATA: CVC Rate 0.01kN/s
****
Source of data:
WS3 File Version: 1.05
Number of bytes in subfile: 355413
Total number of data points: 29586
Test date: 24/04/2009
Test time: 13:31:46
Player Step: 1
Step Capture No: 1
Actuator: 1
****
Actuator: 1 Channel:0, Actuator:
A1 Load : Current (kN),Current (mm), Time (s),
-0.15, -0.174, 0.250,
-0.17, -0.185, 0.594,
-0.17, -0.191, 0.938,
-0.19, -0.213, 1.297,
-0.21, -0.219, 1.610,
-0.24, -0.238, 1.954,
-0.26, -0.254, 2.297,
-0.29, -0.245, 2.625,
-0.30, -0.261, 2.954,
-0.31, -0.243, 3.282,
-0.31, -0.240, 3.610,
-0.31, -0.254, 3.938,
-0.31, -0.287, 4.266,
-0.31, -0.283, 4.594,
-0.31, -0.265, 4.938,
-0.31, -0.216, 5.250,
-0.31, -0.195, 5.579,
-0.31, -0.171, 5.907,
-0.31, -0.175, 6.235,
-0.31, -0.183, 6.563,
-0.31, -0.186, 6.907,
-0.31, -0.193, 7.219,
-0.31, -0.193, 7.547,
-0.31, -0.187, 7.875,
-0.31, -0.197, 8.204,
-0.31, -0.203, 8.532,
-0.31, -0.213, 8.860,
-0.31, -0.215, 9.188,
-0.32, -0.212, 9.516,
-0.32, -0.184, 9.844,
-0.32, -0.184, 10.172,
-0.32, -0.186, 10.500,
-0.32, -0.228, 10.829,
-0.32, -0.258, 11.157,

-0.32, -0.278, 11.485,
-0.33, -0.276, 11.813,
-0.33, -0.229, 12.157,
-0.33, -0.216, 12.469,
-0.33, -0.195, 12.797,
-0.34, -0.166, 13.125,
-0.34, -0.126, 13.454,
-0.35, -0.064, 13.797,

------------Cut----------------------------

-96.50, -111.039, 9712.250,
-96.50, -111.046, 9712.579,
-96.50, -111.056, 9712.907,
-96.27, -111.066, 9713.235,
-96.39, -111.080, 9713.563,
-96.47, -111.093, 9713.891,
-96.52, -111.104, 9714.219,
-96.54, -111.117, 9714.547,
-96.50, -111.124, 9714.875,
-96.47, -111.131, 9715.204,
-96.47, -111.138, 9715.532,
-96.47, -111.146, 9715.860,
-96.48, -111.152, 9716.188,
-96.48, -111.159, 9716.516,
-96.49, -111.166, 9716.860,
-96.49, -111.172, 9717.172,
-96.49, -111.178, 9717.500,
-96.49, -111.184, 9717.829,
-96.50, -111.191, 9718.157,
-96.50, -111.195, 9718.485,
-96.50, -111.201, 9718.813,
-96.50, -111.207, 9719.141,
-96.50, -111.213, 9719.469,
-96.50, -111.217, 9719.797,
-96.50, -111.222, 9720.125,
-96.50, -111.226, 9720.454,
-96.50, -111.232, 9720.782,
-96.49, -111.236, 9721.110,
-96.49, -111.241, 9721.438,
-96.49, -111.246, 9721.766,
-96.49, -111.250, 9722.110,
-96.48, -111.254, 9722.422,

WORKSHOP 3 EXPORTED DATA: SCC
0.01kN/s
****

Source of data:
WS3 File Version: 1.05
Number of bytes in subfile: 372585
Total number of data points: 31017
Test date: 23/04/2009
Test time: 14:39:15
Player Step: 1
Step Capture No: 1
Actuator: 1
****

Actuator: 1 Channel:0, Actuator:
A1 Load : Current (kN), Current (mm), Time (s),
-1.28, -0.019, 0.2650,
-1.30, -0.021, 0.6090,
-1.30, -0.023, 0.9210,
-1.31, -0.020, 1.2650,
-1.32, -0.024, 1.6090,
-1.32, -0.020, 1.9210,
-1.33, -0.018, 2.2500,
-1.34, -0.003, 2.5930,
-1.34, 0.008, 2.9210,
-1.35, 0.017, 3.2500,
-1.36, 0.022, 3.5780,
-1.36, 0.009, 3.9060,
-1.37, 0.003, 4.2340,
-1.37, 0.013, 4.5780,
-1.37, 0.015, 4.9210,
-1.38, 0.020, 5.2500,
-1.39, 0.022, 5.5930,
-1.39, 0.024, 5.9530,
-1.40, 0.029, 6.2650,
-1.40, 0.027, 6.5930,
-1.40, 0.029, 6.9210,
-1.41, 0.035, 7.2650,
-1.41, 0.036, 7.5930,
-1.42, 0.031, 7.9210,
-1.42, 0.018, 8.2500,
-1.42, 0.009, 8.5780,
-1.43, 0.004, 8.9060,
-1.43, -0.002, 9.2340,
-1.44, 0.000, 9.5620,
-1.44, -0.006, 9.9060,
-1.44, -0.007, 10.2500,
-1.44, -0.010, 10.5780,
-1.45, -0.010, 10.9060,

-1.45, -0.010, 11.2340,
-1.45, -0.005, 11.5620,
-1.46, -0.005, 11.8900,
-1.46, -0.002, 12.2340,
-1.46, -0.002, 12.5460,
-1.46, 0.000, 12.8750,
-1.47, -0.001, 13.2030,
-1.47, 0.005, 13.5310,
-1.47, 0.002, 13.8590,
------------Cut-------------------------
-102.78, -32.541, 10174.7600,
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-102.76, -32.636, 10175.4200,
-102.76, -32.680, 10175.7500,
-102.75, -32.719, 10176.0800,
-102.74, -32.761, 10176.4100,
-102.74, -32.808, 10176.7300,
-102.74, -32.851, 10177.0600,
-102.74, -32.887, 10177.3900,
-102.75, -32.905, 10177.7200,
-102.76, -32.916, 10178.0500,
-102.76, -32.928, 10178.3800,
-102.75, -32.957, 10178.7000,
-102.78, -32.986, 10179.0300,
-102.78, -33.028, 10179.3600,
-102.77, -33.096, 10179.6900,
-102.77, -33.157, 10180.0100,
-102.78, -33.161, 10180.3400,
-102.79, -33.232, 10180.6700,
-102.79, -33.302, 10181.0000,
-102.76, -33.377, 10181.3300,
-102.75, -33.404, 10181.6600,
-102.71, -33.525, 10181.9800,
-102.72, -33.667, 10182.3100,
-102.82, -33.819, 10182.6400,
-102.82, -33.916, 10182.9700,
-102.70, -33.797, 10183.3000,
-102.68, -33.848, 10183.6300,
-102.62, -33.902, 10183.9500,
-102.47, -34.082, 10184.2800,
-101.46, -34.608, 10184.6100,
-99.74, -37.120, 10184.9400,
-100.01, -39.534, 10185.2600,
-100.15, -41.816, 10185.5900,
-99.82, -44.085, 10185.9200,
-99.75, -46.387, 10186.2500,
-92.88, -52.503, 10186.5800,
-95.04, -60.948, 10186.9500,
-95.98, -69.122, 10187.3000,
-96.39, -76.229, 10187.6400,

WORKSHOP 3 EXPORTED DATA:CVC
0.2kN/s
****
Source of data:
WS3 File Version: 1.05
Number of bytes in subfile: 19989
Total number of data points: 1634
Test date: 23/04/2009
Test time: 17:09:50
Player Step: 1
Step Capture No: 1
Actuator: 1
****
Actuator: 1 Channel:0, Actuator:
A1 Load : Current (kN), Current (mm), Time (s),
-1.81, -0.700, 0.249,
-1.93, -0.709, 0.577,
-2.06, -0.722, 0.905,
-2.11, -0.736, 1.249,
-2.19, -0.751, 1.562,
-2.26, -0.766, 1.890,
-2.33, -0.778, 2.218,
-2.40, -0.789, 2.546,
-2.48, -0.800, 2.874,
-2.53, -0.809, 3.202,
-2.58, -0.818, 3.530,
-2.64, -0.829, 3.859,
-2.70, -0.837, 4.187,
-2.75, -0.844, 4.530,
-2.79, -0.863, 4.843,
-2.82, -0.886, 5.171,
-2.86, -0.907, 5.499,
-2.91, -0.924, 5.843,
-2.95, -0.945, 6.155,
-2.98, -0.967, 6.484,
-3.18, -0.996, 6.812,
-3.42, -1.022, 7.140,
-3.45, -1.028, 7.468,
-3.43, -1.031, 7.796,
-3.43, -1.032, 8.124,
-3.47, -1.034, 8.452,
-3.51, -1.033, 8.780,
-3.57, -1.036, 9.109,
-3.65, -1.044, 9.437,
-3.71, -1.053, 9.780,
-3.78, -1.059, 10.093,
-3.85, -1.066, 10.421,
-3.92, -1.074, 10.749,

-4.00, -1.082, 11.077,
-4.06, -1.088, 11.405,
-4.13, -1.095, 11.734,
-4.19, -1.098, 12.062,
-4.26, -1.104, 12.390,
-4.33, -1.110, 12.718,
-4.39, -1.116, 13.046,
-4.45, -1.121, 13.374,
-4.52, -1.124, 13.702,

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-99.94, -26.742, 493.374,
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-100.13, -27.576, 494.374,
-100.15, -27.851, 494.702,
-100.15, -28.148, 495.046,
-100.01, -28.598, 495.359,
-98.18, -29.636, 495.702,
-94.45, -34.148, 496.030,
-92.26, -40.367, 496.374,
-58.29, -50.933, 496.702,
-52.37, -67.586, 497.030,
-49.22, -86.963, 497.374,
-98.05, -101.904, 497.734,
-97.43, -107.758, 498.077,
-101.35, -108.801, 498.405,
-101.72, -109.048, 498.734,
-101.66, -109.110, 499.077,
-101.26, -109.120, 499.437,
-101.16, -109.131, 499.749,
-101.02, -109.138, 500.077,
-100.89, -109.142, 500.405,
-100.80, -109.146, 500.734,
-100.73, -109.149, 501.077,
-100.66, -109.151, 501.405,
-100.60, -109.152, 501.734,
-100.53, -109.153, 502.062,
-100.47, -109.154, 502.390,
-100.41, -109.154, 502.718,
-100.36, -109.156, 503.046,
-100.31, -109.156, 503.374,
-100.28, -109.157, 503.702,
-100.25, -109.158, 504.030,
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-100.16, -109.160, 505.015,
-100.14, -109.161, 505.343,
-100.12, -109.162, 505.671,
-100.10, -109.162, 505.999,
-100.08, -109.163, 506.327,

-100.06, -109.163, 506.655,
-100.04, -109.163, 506.984,
-100.02, -109.163, 507.312,
-100.00, -109.164, 507.640,
-99.98, -109.165, 507.968,
-99.97, -109.165, 508.296,
-99.95, -109.165, 508.624,
-99.94, -109.166, 508.952,
-99.92, -109.166, 509.280,
-99.91, -109.167, 509.609,
-99.89, -109.167, 509.968,
-99.88, -109.167, 510.312,
-99.87, -109.168, 510.655,
-99.86, -109.169, 510.999,
-99.85, -109.169, 511.343,
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-99.84, -109.170, 512.030,
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-99.75, -109.177, 517.609,
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-99.72, -109.181, 520.890,
-99.71, -109.181, 521.218,
-99.71, -109.181, 521.562,
-99.70, -109.182, 521.874,
-99.70, -109.182, 522.202,
-99.70, -109.183, 522.530,
-99.69, -109.183, 522.859,

-99.70,	-109.183,	523.187,
-99.70,	-109.184,	523.515,
-99.70,	-109.184,	523.843,
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-99.70,	-109.185,	524.499,
-99.70,	-109.185,	524.827,
-99.70,	-109.186,	525.155,
-99.71,	-109.186,	525.484,
-99.71,	-109.187,	525.812,
-99.71,	-109.187,	526.140,
-99.70,	-109.188,	526.468,
-99.70,	-109.188,	526.827,
-99.70,	-109.189,	527.140,
-99.70,	-109.189,	527.468,
-99.70,	-109.189,	527.812,
-99.70,	-109.190,	528.155,
-99.70,	-109.190,	528.499,
-99.70,	-109.191,	528.843,
-99.70,	-109.191,	529.171,
-99.70,	-109.191,	529.499,
-99.71,	-109.192,	529.827,
-99.71,	-109.192,	530.155,
-99.71,	-109.193,	530.499,
-99.70,	-109.193,	530.827,
-99.70,	-109.194,	531.155,
-99.70,	-109.194,	531.499,
-99.70,	-109.195,	531.827,
-99.70,	-109.194,	532.155,
-99.70,	-109.195,	532.484,
-99.70,	-109.195,	532.812,
-99.70,	-109.196,	533.140,
-99.70,	-109.196,	533.468,
-99.69,	-109.196,	533.796,
-99.69,	-109.196,	534.124,
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-99.69,	-109.197,	534.780,
-99.68,	-109.197,	535.109,
-99.69,	-109.198,	535.437,
-99.69,	-109.198,	535.765,
-99.70,	-109.199,	536.093,
-99.70,	-109.199,	536.421,
-99.70,	-109.200,	536.749,
-99.71,	-109.200,	537.077,
-99.70,	-109.200,	537.405,
-99.70,	-109.200,	537.734,
-99.70,	-109.201,	538.062,

WORKSHOP 3 EXPORTED DATA: SCC 0.2kN/s

****

Source of data:
WS3 File Version: 1.05
Number of bytes in subfile: 21081
Total number of data points: 1725
Test date: 24/04/2009
Test time: 10:11:19
Player Step: 1
Step Capture No: 1
Actuator: 1

****

Actuator: 1 Channel:0, Actuator:
A1 *Load* : *Current* (kN), *Current* (mm), *Time* (s
-0.87, -0.144, 0.2500,
-1.03, -0.166, 0.5780,
-1.17, -0.188, 0.9060,
-1.24, -0.201, 1.2500,
-1.25, -0.213, 1.5630,
-1.27, -0.188, 1.8910,
-1.30, -0.182, 2.2190,
-1.33, -0.195, 2.5470,
-1.38, -0.192, 2.8750,
-1.43, -0.213, 3.2030,
-1.50, -0.215, 3.5310,
-1.56, -0.030, 3.8590,
-1.63, -0.107, 4.1880,
-1.70, -0.151, 4.5160,
-1.77, -0.187, 4.8440,
-1.86, -0.226, 5.1720,
-1.93, -0.252, 5.5000,
-2.00, -0.273, 5.8280,
-2.06, -0.245, 6.1560,
-2.11, -0.198, 6.5000,
-2.17, -0.213, 6.8130,
-2.23, -0.172, 7.1410,
-2.29, -0.188, 7.4690,
-2.34, -0.214, 7.7970,
-2.41, -0.258, 8.1250,
-2.48, -0.276, 8.4530,
-2.55, -0.295, 8.7810,
-2.61, -0.309, 9.1090,
-2.68, -0.306, 9.4530,
-2.76, -0.289, 9.7660,
-2.83, -0.303, 10.0940,
-2.90, -0.318, 10.4220,
-2.97, -0.330, 10.7500,
-3.03, -0.315, 11.0940,
-3.10, -0.284, 11.4060,
-3.17, -0.294, 11.7340,

-3.23, -0.312, 12.0630,
-3.29, -0.336, 12.3910,
-3.35, -0.357, 12.7190,
-3.42, -0.373, 13.0470,
-3.49, -0.382, 13.3750,
-----------Cut------------------------------
-111.26, -29.438, 553.9060,
-111.31, -29.633, 554.2340,
-111.35, -29.834, 554.5630,
-111.37, -30.040, 554.8910,
-111.35, -30.303, 555.2190,
-111.44, -30.581, 555.5470,
-111.46, -30.871, 555.8750,
-111.46, -31.189, 556.2030,
-111.49, -31.552, 556.5310,
-111.54, -31.981, 556.8590,
-111.57, -32.374, 557.1880,
-111.58, -32.781, 557.5310,
-111.42, -33.306, 557.8590,
-111.34, -33.926, 558.2030,
-111.43, -34.608, 558.5310,
-111.29, -35.414, 558.8590,
-110.89, -36.365, 559.2030,
-110.63, -37.545, 559.5310,
-106.53, -39.326, 559.8590,
-108.79, -42.912, 560.2030,
-108.78, -46.255, 560.5630,
-105.55, -50.174, 560.8910,
-105.94, -56.431, 561.2340,
-106.03, -62.881, 561.5940,
-105.22, -69.058, 561.9060,
-105.22, -75.952, 562.2340,
-103.24, -84.731, 562.5780,
-108.56, -94.244, 562.9380,
-112.28, -97.472, 563.2810,
-113.32, -98.960, 563.6090,
-114.08, -99.854, 563.9530,
-114.33, -100.135, 564.2810,
-114.33, -100.263, 564.6090,
-114.23, -100.347, 564.9530,
-114.16, -100.403, 565.2810,
-114.06, -100.444, 565.6090,
-113.96, -100.481, 565.9380,
-113.88, -100.510, 566.2660,
-113.80, -100.535, 566.5940,
-113.73, -100.558, 566.9220,
-113.66, -100.579, 567.2500,
-113.59, -100.601, 567.5780,
-113.54, -100.620, 567.9060,

WORKSHOP 3 EXPORTED DATA: CVC 15kN/s

****

Source of data:
WS3 File Version: 1.05
Number of bytes in subfile: 3153
Total number of data points: 231
Test date: 23/04/2009
Test time: 16:30:47
Player Step: 1
Step Capture No: 1
Actuator: 1

****

Actuator: 1 Channel:0, Actuator:
A1 *Load : Current* (kN), *Current* (mm), *Time* (s),
-19.59, -1.104, 0.2495,
-24.73, -1.577, 0.6085,
-29.62, -2.076, 0.9375,
-35.21, -2.606, 1.2805,
-39.72, -3.043, 1.6085,
-44.64, -3.509, 1.9375,
-50.11, -4.021, 2.2805,
-54.98, -4.466, 2.6085,
-59.79, -4.904, 2.9525,
-65.24, -5.381, 3.2805,
-70.00, -5.796, 3.6085,
-74.60, -6.204, 3.9525,
-80.06, -6.690, 4.2805,
-84.81, -7.119, 4.6085,
-89.54, -7.567, 4.9375,
-94.89, -8.194, 5.2805,
-97.56, -9.197, 5.6085,
-102.69, -11.302, 5.9375,
-104.18, -14.743, 6.2655,
-106.45, -20.348, 6.6085,
-108.78, -29.146, 6.9215,
-107.66, -40.775, 7.2495,
-106.65, -57.741, 7.6085,
-86.91, -74.791, 7.9375,
-112.98, -93.660, 8.2805,
-131.65, -107.729, 8.6405,
-141.09, -111.154, 8.9685,
-99.93, -119.957, 9.3125,
-27.00, -139.254, 9.6715,
0.43, -156.060, 9.9835,
-3.75, -172.292, 10.3125,
-4.71, -189.618, 10.6405,
-5.42, -205.797, 10.9685,
-8.26, -221.900, 11.2965,
-3.56, -237.437, 11.6245,
-2.98, -252.018, 11.9525,

-1.99, -265.473, 12.2805,
-0.85, -264.472, 12.6085,
-0.58, -263.940, 12.9375,
-0.46, -263.666, 13.2655,
-0.38, -263.507, 13.5935,

WORKSHOP 3 EXPORTED DATA: SCC
15kN/s
****
Source of data:
WS3 File Version: 1.05
Number of bytes in subfile: 2829
Total number of data points: 204
Test date: 23/04/2009
Test time: 15:13:56
Player Step: 1
Step Capture No: 1
Actuator: 1
****
Actuator: 1 Channel:0, Actuator:
A1 Load : Current (kN), Current (mm), Time (s)
-17.83, -0.756, 0.2650,
-22.55, -0.934, 0.5930,
-27.02, -1.189, 0.9210,
-31.83, -1.696, 1.2500,
-37.25, -2.144, 1.5930,
-41.95, -2.578, 1.9210,
-46.77, -3.078, 2.2500,
-52.32, -3.518, 2.5780,
-57.12, -3.945, 2.9210,
-62.37, -4.417, 3.2650,
-67.14, -4.852, 3.5930,
-72.09, -5.301, 3.9210,
-76.99, -5.739, 4.2500,
-82.14, -6.219, 4.5930,
-86.93, -6.666, 4.9210,
-92.24, -7.193, 5.2650,
-96.70, -7.752, 5.5930,
-97.73, -9.861, 5.9210,
-102.27, -14.052, 6.2650,
-104.76, -20.684, 6.6250,
-97.09, -30.390, 6.9530,
-101.97, -46.691, 7.2810,
-101.06, -63.116, 7.6090,
-100.82, -82.215, 7.9370,
-115.32, -98.693, 8.2650,

-132.25,	-104.397,	8.5930,
-133.75,	-105.143,	8.9210,
-133.92,	-105.372,	9.2500,
-133.83,	-105.488,	9.5780,
-133.55,	-105.537,	9.9060,
-133.39,	-105.570,	10.2340,
-133.31,	-105.597,	10.5620,
-133.20,	-105.620,	10.8900,
-133.12,	-105.637,	11.2180,
-133.06,	-105.654,	11.5460,
-133.02,	-105.668,	11.8900,
-132.97,	-105.682,	12.2030,
-132.92,	-105.694,	12.5310,
-132.85,	-105.703,	12.8750,
-132.78,	-105.712,	13.1870,
-132.71,	-105.719,	13.5150,
-132.65,	-105.725,	13.8430,
-131.99,	-106.131,	51.1560,
-131.99,	-106.134,	51.4840,
-132.00,	-106.136,	51.8120,
-132.00,	-106.139,	52.1400,
-132.00,	-106.142,	52.4680,
-132.00,	-106.144,	52.7960,
-132.01,	-106.147,	53.1250,
-132.01,	-106.149,	53.4530,
-132.01,	-106.151,	53.7810,
-132.00,	-106.153,	54.1090,
-132.00,	-106.155,	54.4370,
-132.01,	-106.158,	54.7810,
-132.01,	-106.160,	55.0930,
-132.01,	-106.162,	55.4210,
-132.02,	-106.164,	55.7650,
-132.02,	-106.166,	56.0930,
-132.02,	-106.168,	56.4060,
-132.02,	-106.171,	56.7340,
-132.02,	-106.173,	57.0620,
-132.02,	-106.175,	57.3900,
-132.02,	-106.177,	57.7180,
-132.02,	-106.180,	58.0460,
-132.02,	-106.182,	58.3750,
-132.03,	-106.183,	58.7030,
-132.03,	-106.185,	59.0460,
-132.03,	-106.188,	59.3590,
-132.03,	-106.190,	59.6870,
-132.03,	-106.193,	60.0150,
-132.03,	-106.195,	60.3430,
-132.04,	-106.197,	60.6710,
-132.04,	-106.199,	61.0000,
-132.04,	-106.202,	61.3280,
-132.04,	-106.204,	61.6560,

-132.04,	-106.206,	61.9840,
-132.03,	-106.208,	62.3120,
-132.03,	-106.210,	62.6400,
-132.02,	-106.212,	62.9680,
-132.03,	-106.215,	63.2960,
-132.03,	-106.217,	63.6250,
-132.04,	-106.219,	63.9530,
-132.04,	-106.222,	64.2960,
-132.05,	-106.224,	64.6090,
-132.05,	-106.226,	64.9370,
-132.05,	-106.228,	65.2650,
-132.05,	-106.230,	65.5930,
-132.05,	-106.232,	65.9210,
-132.04,	-106.234,	66.2500,
-132.04,	-106.236,	66.5780,
-132.04,	-106.238,	66.9060,
-132.04,	-106.240,	67.2340,
-132.04,	-106.242,	67.5620,
-132.04,	-106.244,	67.8900,

APPENDIX 3

Gantt Chart

APPENDIX 3-1

Gantt Chart for FYP I

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	***Selection of Project Topic***	■	■													
	Title Selection		■													
	Proposal of Topic Selection		■	■												
	Preliminary Research Work			■	■											
	Confirmation of Topic Selection			■	■											
2	***Project Research***		■	■	■	■										
	Data Selection			■	■	■	■									
	Identify materials and Researches			■	■	■	■									
	Literature Reviews			■	■	■	■									
	Researches and Gather information			■	■	■	■									
	Preliminary/Progress Report Preparation						●									
3	***Project Work***						■	■	■	■	■	■	■			
	Preparation of Materials and Researches						■	■	■	■	■	■	■			
	Lab Work 1:Cube Concrete Preparation						■	■	■	■	■	■	■			
	Beam Design Researches						■	■	■	■	■	■	■			
4	***Ending of FYP I***															
	Interim Report (Final Draft) Preparation						■	■	■	■	■	■	●			
	Preparation and finalize FYP I								■	■	■	■	■	■	■	
	Oral Presentation Preparation											■	■	■	■	●

● Suggested milestone

■ Process

Gantt Chart for FYP II

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	***Project Work Continue***														
	Lab Work 2: Beam Preparation 1	■	■												
	Supplementary Literature Researches 1	■	■	■											
	Lab Work 3: Beam Preparation 2	■	■	■	■	■	■	■							
	Preparation & Submission Progress Report		■	■	■	■	●								
	Lab Work 4: Beam Testing				■	■	■	■	■	■	■	■	■	■	
2	***Project Work and Analysis***				■	■	■	■	■	■	■	■	■	■	
	"Data Collection, analysis and Researches"				■	■	■	■	■	■	■	■	■	■	
	Poster Presentation Preparation										●				
	Supplementary Literature Researches 2				■	■	■	■	■	■	■	■	■	■	
3	***Ending of FYP II***														
	Prepare Dissertation Report					■	■	■	■	■	■	■	●		
	Preparation and finalize FYP II											■	■	●	
	Oral Presentation												■	■	●

● Suggested milestone

■ Process